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THREE MECHANISMS OF BREAKDOWN OBTAINED ON GLASS BY ELIMINATION OF EDGE EFFECT.

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THE development of our present theories of breakdown of solid dielectrics is not without interest. In the earlier days electric breakdown was thought to be somewhat analogous to the failure of materials by mechanical stress, and every substance was believed to have a definite breakdown gradient at which failure occurred. Experience soon proved this idea to be untenable; and further tests were so complicated by the effect of factors such as edge breakdown, variation in rate of voltage application, imperfect contact with the dielectric, and variation of electrode area that the subject remained in a state of almost complete chaos until 1922.

At that time K. W. Wagner presented his epochal paper on breakdown as a process of thermal instability, which contribution aroused the dormant interest in the subject and resulted in marked progress on both theoretical and experimental sides. Papers by Kármán, Rogowski, Fock and others revised the thermal theory and placed it on a firmer basis; while the experimental work of Inge and Walther on glass, rock salt, and porcelain verified the principal predictions of the theory.

It was soon realized, however, that the thermal theory could not offer a complete explanation of breakdown.* In

* See, for instance, Bibliography 3.

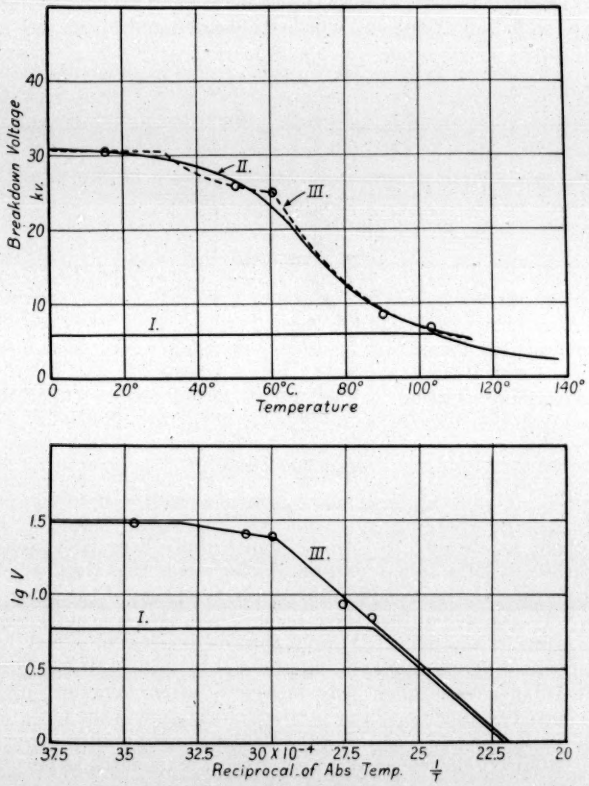
fact, the experiments of Inge and Walther[2] showed that at low temperatures the thermal theory ceased to apply and breakdown voltage became independent of temperature. Attempts to explain these low-temperature breakdowns lead to the ionization-by-collision theory of Joffé and the molecular disruption theory of Rogowski.

The experimental results of Inge and Walther, however, were open to the objection that at low temperatures the punctures occurred at the electrode edge in a field of unknown strength. Quantitatively, then, the tests were of doubtful value. Thus, the next step of these investigators was to repeat the tests with improved methods which eliminated "edge effect" and caused failure to occur in a uniform field. In 1904 Mościcki[4] eliminated edge breakdown by blowing thin portions in glass tubes. His method, somewhat modified, was used by Inge and Walther[1] in 1928. They also eliminated edge effect by immersing the specimen and electrodes in a bath of correct resistivity. The great increase in apparent breakdown gradient caused by the elimination of edge effect is shown in Fig. 1. Here the lower curve (I) was obtained in the ordinary manner, the breakdowns for the horizontal portion being at the electrode edge. Curve II was obtained with edge effect eliminated and gives at room temperature voltages five times as great as those previously obtained, notwithstanding the fact that the thickness of the specimens used for II was only half that of the samples for I. Thus by eliminating edge effect, Inge and Walther raised the breakdown gradient to ten times its former value. Similar ratios will be found by comparing their gradient of 3000 kv./cm. with tabulated values such as those in the Smithsonian Physical Tables.

In the older tests shown by Curve I of Fig. 1, the region to the right was proved to be thermal breakdown while the horizontal curve represented a different mechanism which might be called "disruptive." In Curve II, however, it will be noted that the sharp break between the two mechanisms has entirely disappeared and there is an intermediate region of uncertain character. Inge and Walther believed this to be a combination of thermal and disruptive breakdown—a region of "thermo-electric" breakdown.

Valuable as the Inge and Walther results are, the five points they give are not sufficient to determine the shape of the voltage-temperature curve to any precision. The purpose of this investigation, then, was to study the intermediate

FIG. 1.



Breakdown Voltage of Glass

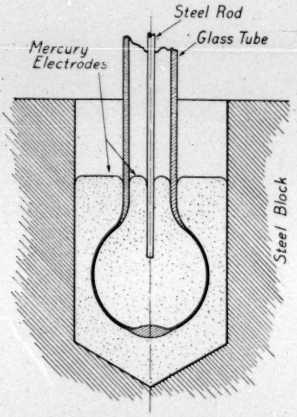
I. Inge and Walther, 200 μ Object Glass without elimination of edge effect.
II. Inge and Walther, 100 μ Cover Glass in Semiconducting Bath.
III. Same data as II, but curve drawn with slopes obtained for G-1 glass.

region in more detail by varying the temperature through a wider range and obtaining a larger number of points. The tests were made in the Electrical Research Laboratories of the Massachusetts Institute of Technology.

APPARATUS.

The form of glass samples is shown in Fig. 2. Glass tubing was sealed off at one end which was heated and blown into a

FIG. 2.



Form of Glass Sphere used for Breakdown Tests.

sphere as shown. It will be noted that there is a comparatively large area of uniform thickness and that the change from the thickness of the tube to the thickness of the sphere is very gradual so that there is no appreciable concentration of stress at any point. Various thicknesses were obtained by blowing different diameter bubbles and by using various sizes of tubing. Thickness was measured after puncture had occurred by breaking away portions of the glass in the vicinity of the failure and measuring the thickness with a micrometer.

Mercury electrodes were used in most of the tests, although other materials were used in some cases.* Contact to the

* See page 719.

inner electrode was made by a steel rod which was so hung that it would not rest on the bottom of the sphere. The mercury for the outer electrode was held in a well about 3.8 cm. in diameter which was bored in a piece of steel shafting 15 cm. in diameter and 15 cm. long. This large steel cylinder was well insulated thermally and proved to be very effective in keeping the temperature uniform.

For testing flat sheets, brass electrodes were used, the diameter of the flat portion being 15.9 mm. and the radius of the rounded edge being 3.2 mm. These were immersed in a liquid having the proper resistivity to prevent edge breakdown.

All tests were made with direct potential obtained either from a 100-kv. kenotron set or from a 4000-volt motor-generator set. Voltage was measured with a 20-kv. voltmeter of the D'Arsonval type or with a 100-kv. electrostatic meter.

With the kenotron set, voltage was brought up slowly by the use of an induction regulator in the primary of the transformer. In some of the tests a motor-driven rheostat was also used. At low temperatures the rate of voltage rise had little if any effect, but at higher temperatures it was found necessary to use a much lower rate of voltage application. A uniform rise giving breakdown in about ten minutes was found satisfactory.

EXPERIMENTAL RESULTS.

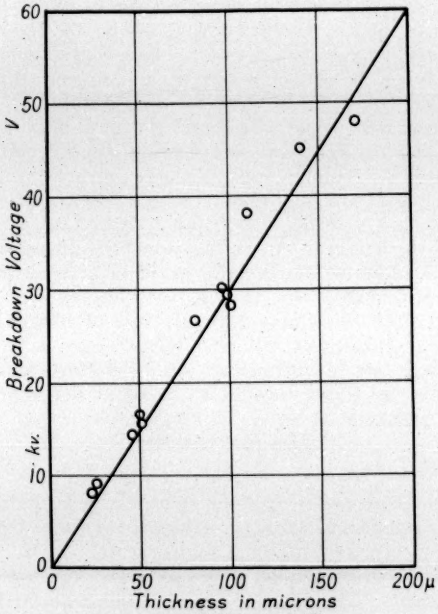
Tests on G-1 Glass.

The first tests were made on G-1 glass (a lead glass made by the Corning Glass Works). The *points* of Fig. 3 represent the results obtained at room temperature. Here, as in all subsequent curves, each point indicates one breakdown measurement. The unit of voltage is taken as the kilovolt, and the unit of thickness is the micron. ($1\ \mu = 0.001$ mm.) The *curve* was taken from Inge and Walther's tests on two different kinds of glass, and will be seen to agree closely with the tests on G-1 glass. Inge and Walther obtained an average breakdown gradient of 3000 kv./cm., while our average was 3100 kv./cm. This check was considered a sufficiently good indication that edge effect was eliminated, and accordingly the work was extended to higher temperatures.

The results of all tests on G-1 glass are shown in Fig. 4. where breakdown voltage is plotted against thickness. Several striking facts are at once evident.

1. For low temperatures and small values of thickness a linear relation holds, as shown by the curve for 0 deg. cent.

FIG. 3.



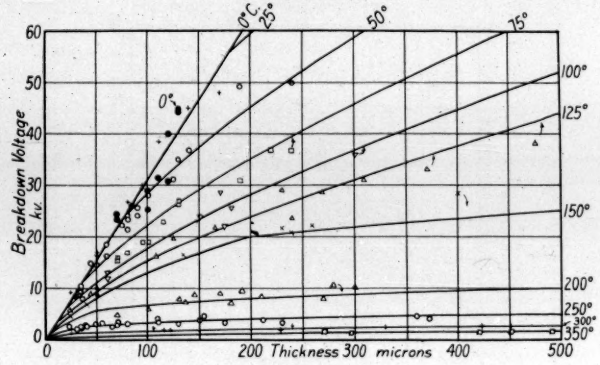
Breakdown Voltage of Glass at 20 deg.cent.

The straight line was obtained by Inge and Walther [1] on the following:
1. Cover glass in xylene, 50 cycles, peak values.
2. Lime glass spheres, 50 cycles, peak values.
3. Lime glass spheres, direct potential.
Curves for these three conditions coincide.
The points were obtained by Moon and Norcross for G-1 glass on direct potential.

The voltage gradient for this condition is constant at the high value of 3100 kv./cm. and is independent of both thickness and temperature.

2. For higher temperature and greater thickness, the breakdown voltage is no longer independent of temperature, but decreases as the temperature is raised.

FIG. 4.



Breakdown Voltage of Lead Glass Spheres (G-1 glass).

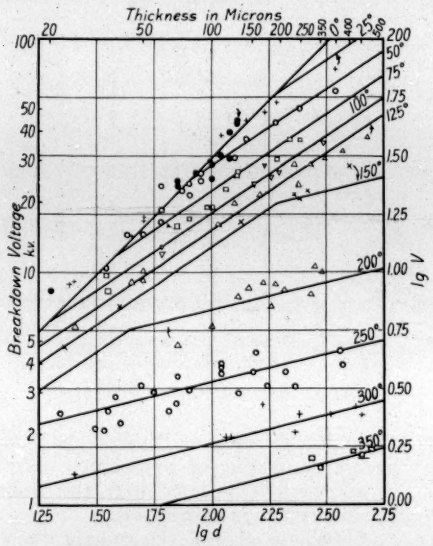
3. Above 150 deg. the spacing between the curves shows a sudden increase, indicating an augmented effect of temperature. It will be shown later that the transition to thermal breakdown occurs in this region.

The curves branching off from the straight line are of the form $V = ad^n$ where a and n were chosen to fit the majority of the points. It is true that the points at very great thickness appear to be slightly low, but it was not thought that the accuracy of the data warranted a more complicated expression than the above.

The same results are plotted in Fig. 5 where logarithmic scales are used so that all curves will plot as straight lines. The straight line on the left is for disruptive breakdown and has the slope ($n = 1.00$). The group of lines on the upper part of the diagram were at first drawn with slightly different slopes with n varying from about 0.7 to about 0.6. However, the points seemed to be fitted a little better if all these lines were drawn parallel; and when this was done, n was found

to be $\frac{2}{3}$. In the lower part of the figure, the lines are evidently of quite different slope. The simplest result is obtained by drawing these parallel with a slope of $\frac{1}{4}$. Fig. 5

FIG. 5.



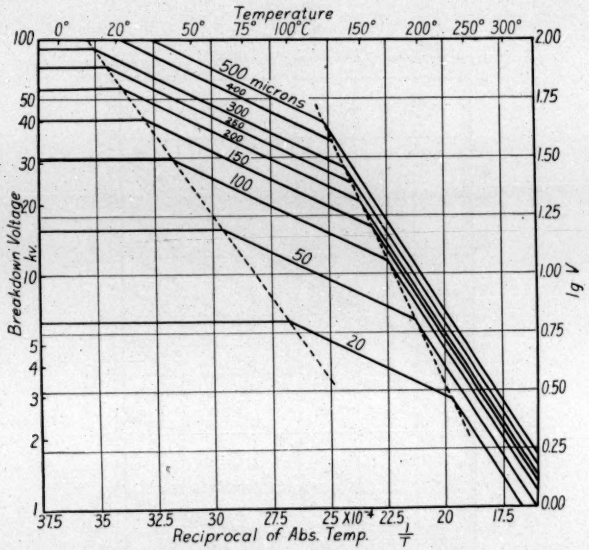
Breakdown Voltage of Lead Glass Spheres (G–1 glass).

thus indicates three mechanisms of breakdown—disruptive breakdown shown by the straight line with unit slope, thermal breakdown shown by the lower lines with slope $\frac{1}{4}$, and another mechanism indicated by the group of parallel lines with slope $\frac{2}{3}$.

These are shown to better advantage in Fig. 6 where the same curves are plotted against the reciprocal of the absolute temperature. For simplicity, all experimental points have been omitted, the values used for these curves being taken directly from the curves of Fig. 5. On the left the breakdown voltage is seen to be independent of temperature (disruptive

breakdown).* On the right the voltage decreases very rapidly as temperature increases. The slope of these curves

FIG. 6.



Breakdown Voltage of Lead Glass Spheres (G-1 glass).

is approximately that predicted by the thermal theories. Between these two regions is a third one, distinct from the other two and, to the best of the authors' knowledge, here described for the first time.

Results on Lime Glass.

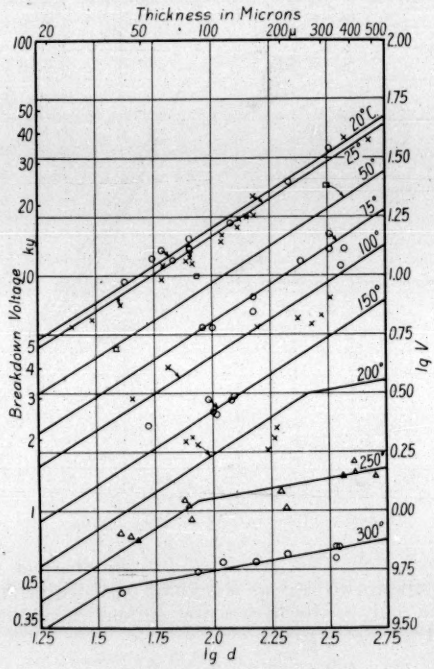
To make sure that the intermediate region was not due to some peculiarity of the glass, further tests were made on ordinary laboratory glass tubing (sodium-lime glass). Spheres were blown as before. As shown in Figs. 7 and 8, the curves are similar to the previous ones.

* Further tests at − 60 deg. gave the same results as those obtained at 0 deg.

Tests on Flat Sheets.

Tests were then made on microscope cover glass of German manufacture. The sheets were about 4 cm. square and had

FIG. 7.

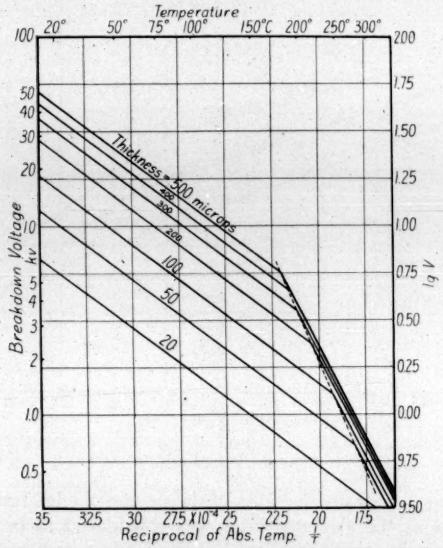


Breakdown Voltage of Lime Glass Spheres.

an average thickness of 200 microns. The electrodes and sample were immersed in a mixture of aniline and xylene, the aniline being added gradually until tests showed that edge effect was eliminated. For temperatures above 100 deg. cent., a heavy lubricating oil (Mobiloil "E") was used.

Within the temperature range of 100 deg. to 200 deg. this had a satisfactory resistivity without the addition of any adulterant. At temperatures above 200 deg. molten paraffin

FIG. 8.



Breakdown Voltage of Lime Glass Spheres.

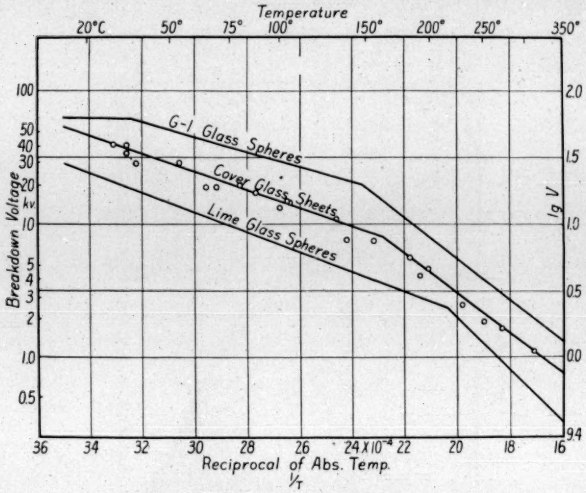
was employed while at 312 deg. tests were made in air. There seemed to be very little difficulty in eliminating edge effect at high temperatures, but the difficulty increased rapidly as the temperature was lowered and the voltage raised.

The results of the tests on cover glass are given in Table I. and are plotted in Fig. 9 which also gives curves for G-1 and lime-glass spheres.

It will be noted that all three curves are of the same shape and show the intermediate as well as the thermal mechanism. If the temperature had been reduced sufficiently on the cover glass and lime glass it is highly probable that these would

also show a region independent of temperature as did the G-1 glass.

FIG. 9.



Breakdown Voltage of various glasses 200 μ thick.

To get a quantitative idea of the degree of edge breakdown elimination, the electrode face was considered to be divided into the ten concentric rings of equal area which were numbered from the center outward. With a very large number of tests, one would expect approximately the same number of punctures to occur in each ring if edge effect is entirely eliminated; while if edge effect is only partially eliminated there should be a distinct preponderance of punctures around Ring 10. The actual results are shown in Table II, which indicates that there was little if any concentration at the edge.

Effect of Electrolytic Polarization.

It is a well-known fact that glass conducts electrolytically, the sodium ion being chiefly responsible for the conduction.[8] Before the application of a voltage, the ions are distributed

at random throughout the glass. If a direct voltage be now applied to electrodes which are insoluble in the glass, the ions drift under the action of the outer field and gradually produce poorly-conducting layers near the electrodes. Thus the apparent resistivity of the glass decreases with time; its

TABLE I.

Breakdown Tests on Cover Glass.

Sample No.	d (microns).	θ (deg. Cent.).	V (kv.).	$\frac{1}{T}$.	$lg\ V.$*	Distance from Edge (mm.).
			In xylene + aniline.			
1	160	87.0	14.8	27.7×10^{-4}	1.234	+3.1
2	205	104.0	14.8	26.5	1.162	2.3
3	160	104.5	12.3	26.4	1.154	−1.0
4	230	100.5	14.5	26.8	1.120	+2.2
5	175	80.0	18.0	28.3	1.293	1.5
6	235	69.0	21.0	29.2	1.275	−1.5
7	228	64.0	20.5	29.6	1.273	+0.5
8	224	53.0	31.0	30.6	1.457	3.9
9	242	32.5	38.0	32.6	1.524	2.1
10	185	29.0	32.5	33.1	1.542	3.5
11	240	33.0	44.0	32.6	1.587	0.6
12	170	37.0	25.0	32.2	1.444	−0.2
			In Mobiloil "E."			
13	190	139.0	8.3	24.2	0.934	+4.1
14	190	134.0	10.5	24.6	1.035	6.0
15	230	157.0	8.2	23.2	0.873	1.3
16	200	184.0	5.5	21.8	0.740	4.2
17	230	195.0	4.30	21.4	0.603	6.2
18	212	201.0	4.65	21.1	0.655	3.5
			In paraffin.			
19	150	231.0	2.15	19.8	0.394	−0.2
20	240	254.0	2.00	19.0	0.261	+3.4
21	210	271.0	1.70	18.3	0.219	
			In air.			
22	225	312.0	1.17	17.1	0.042	6.5

V is actual breakdown voltage, $lg\ V$* is corrected to a common base of 200 μ thickness.

conductivity may finally reach a value thousands of times greater than it had originally. The thickness of these layers is also a function of the applied voltage, causing the apparent resistivity to decrease as the applied voltage is increased. Thus these two familiar characteristics of glass are explained, at least to some extent, by electrolytic polarization.

TABLE II.

Frequency Distribution for Punctures of Cover Glass.

Ring Number.	Number of Punctures.
1	3
2	0
3	3
4	4
5	0
6	3
7	1
8	1
9	2
10	0
11	2
12	0
13	1
14	1
Unknown	1
Total	22

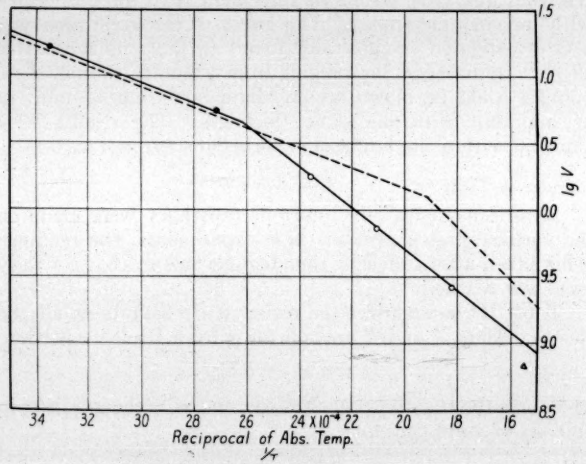
For many years it has been known that all, or most, of the polarization in glass can be eliminated by using an anode which will supply the glass with sodium ions as fast as they are withdrawn from the anode layer by the action of the field. The sodium ions will then pass completely through the glass from anode to cathode and the distribution of potential through the thickness of the specimen will be practically linear. Such non-polarizing electrodes have been used to some extent in conductivity measurements; but as far as the writers can find, have not been applied to breakdown experiments.

One of the purposes of these tests was to find if electrolytic polarization had a marked effect on breakdown voltage, and to make sure that the intermediate region was not in any way due to such phenomena. Glass bubbles were used as

before. The first tests were made at about 370 deg. with molten $NaNO_3$ electrodes. Polarization appeared to be eliminated: absolutely no change of current with time could be detected, and Ohm's law applied. Moreover, the current was greatly increased over its value with ordinary electrodes, a bubble of 30 μ thickness and 2 cm. diameter having a resistance of only 65 ohms. As would be expected, this greatly increased current caused greater heating and lower breakdown voltage.

At lower temperatures, electrodes of sodium amalgam and of an aqueous solution of Na_2SO_4 were used. Various thick-

FIG. 10.



Effect of Electrolytic Polarization on breakdown of lime glass 100 μ thick.
○ Na amalgam electrodes.
• Na amalgam, also Na_2SO_4 solution.
△ Molten $NaNO_3$.
Dotted curve obtained with Hg electrodes.

nesses of glass were tested and curves similar to Figs. 5 and 6 were obtained. Only the 100 μ curve is reproduced here. (Fig. 10.) It will be noted that in the intermediate region the breakdown voltage is practically unchanged by the elimination of polarization, while in the thermal region the

voltage is greatly reduced. This serves as another indication that *the intermediate mechanism is not a combination of the other two but is a distinct entity.*

A few tests with Pyrex and G-1 glass showed a similar reduction in breakdown voltage. A 162 μ sample of G-1 which would normally fail at 1000 volts, broke down at 400 volts with non-polarizing electrodes. Pyrex of 230 μ and 295 μ punctured at 400 and 450 volts, respectively. This would indicate that the sodium ion is largely responsible for the conduction in these glasses as well as in lime glass.

Other electrode materials, such as Wood's metal and ordinary solder at high temperatures and dilute HCl at low temperatures, gave results in agreement with those obtained with mercury electrodes. The effect of electrode area was also investigated roughly and found to have no noticeable effect. By using tubing ranging from 4 mm. to 18 mm. bore, bubbles could be blown having diameters from 10 mm. to 37 mm. but with the same thickness. The results were identical within the limits of experimental error.

Resistivity Tests

Measurements of direct-current resistivity were made on the various glasses used in these experiments, the readings being taken after sufficient time had elapsed so that a steady state was reached.

Table III summarizes the resistivity constants of all the glasses. Here A and B are constants from Poole's equation:

$$lg\ \rho = A - BX,$$

where ρ is the resistivity in ohm-cm. and X is the gradient in millions of volts per cm.

TABLE III.

Resistivity of Various Glasses.

	Temp.	A.	B.
Lime glass No. 19	27.6 deg.	11.55	1.37
" " " 20	27.8	11.35	1.41
" " " 23	30.0	11.63	1.37
G-1 glass No. 8	24.5	14.86	1.20
Pyrex No. 10	24.0	13.80	1.60
Cover glass No. 22	29.0	12.71	1.23
" " (measured by Poole)	29.0	12.82	1.33

It is seen that the values of B are all very nearly the same and are in agreement with values obtained by Poole.[5] The values of A ($A = lg\ \rho$ at zero gradient) are lowest for lime glass, somewhat higher for cover glass, and very much higher for G-1. Other samples of G-1 gave approximately the same resistivity which is over a thousand times as high as that of lime glass.

Summary of Results.

For each region, the breakdown voltage is given by a relation of the form:

$$V = K_i d^{n_i} (10)^{b_i/T},$$

where d is the thickness in microns, T is the absolute temperature, and K_i, n_i and b_i are constants of the material, different for each region. A tabulation follows:

TABLE IV

Material.	Disruptive Breakdown.			Intermediate.		Thermal Breakdown.	
	K_1.	n_1.	b_1.	n_2.	b_2.	n_3.	b_3.
G-1 glass	3100 kv./cm.	1.00	0	0.66	470	0.25	1540
Lime glass				0.63	735	0.185	1910
Lime glass (non-polarizing electrodes)				0.63	735	0.45	1530
Cover glass					687		1500
Pyrex	4800	1.00	0	0.70	715		

Apparently there is no connection between resistivity and breakdown in the disruptive region. Glasses of widely different resistivities may puncture at the same gradient, as would be expected if this is a process of molecular disruption. However, a comparison of Fig. 9 and Table III shows in the intermediate and thermal regions a direct correlation between resistivity and breakdown voltage. G-1 glass which has the highest resistivity has also the greatest breakdown strength, while the other glasses are progressively lower as their resistivities are lower.

Table IV offers a possible explanation of the discrepancies

obtained in the past in regard to the effect of thickness. Some investigators have found that breakdown voltage varies as the first power of the thickness, others are equally sure that the $\frac{2}{3}$ power is the correct one, while others favor the square root of thickness. Of course, tests made without edge effect elimination are of questionable value. Nevertheless, it is possible that those tests which have an exponent of unity were disruptive breakdowns, those that gave $\frac{2}{3}$ were intermediate breakdowns, while those that gave $\frac{1}{2}$ or lower were themal breakdowns.

THE THREE MECHANISMS.

Further reference to Fig. 1 shows, in addition to the Inge and Walther curves I and II, a curve III which has been drawn to fit their five points using the slopes obtained for G-1 glass. It will be noted that the broken curve fits their points at least as well as their smooth curve. Thus the only experimental results with which the present tests can be compared tend to verify them rather than otherwise. Apparently other investigators have not found this intermediate region because edge breakdown has prevented them from obtaining the high gradients of III.

The phenomena may be visualized as shown in Fig. 11. Here the heavy curve represents the breakdown voltage of glass at various temperatures, I being disruptive, III thermal, and II the intermediate mechanism. It is probable that if some means could be devised to suppress II and III, all breakdowns would be disruptive as shown by the dotted line I. On the other hand, if mechanism I could be suppressed at low temperatures, the higher voltages of II or III might be realized. The heavy line is obtained actually because that mechanism is selected which results in the lowest breakdown voltage. For some other material it is possible that the three curves might be as represented in Fig. 11b. Here II cannot be obtained experimentally unless some means is found for suppressing either I or III. In general, however, it seems likely that three mechanisms will be present in other uniform materials. Such a supposition can be verified only by a great number of careful experiments on different materials with edge effect eliminated, aided as much as possible by theories of the three mechanisms.

FIG. 11a.

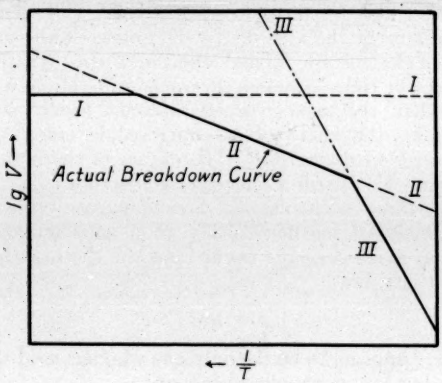
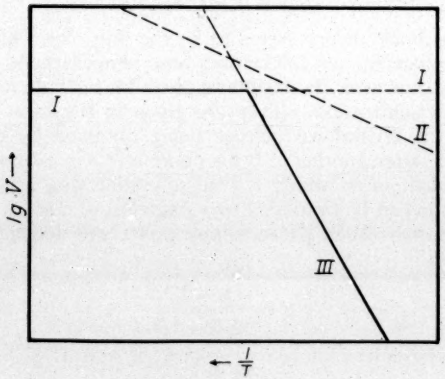


FIG. 11b.



The Three Mechanisms

I. Disruptive
II. Intermediate
III. Thermal

As previously stated, two theories have been advanced to explain Region I. Joffé considers it to be due to ionization by collision like the breakdown of a gas,[6] while Rogowski[7] and others favor the idea of the disruption of the molecules because of electrostatic forces. Neither theory is satisfactory at the present time, although several considerations lead us to believe that the molecular disruption theory[7] (possibly modified by the effect of sub-microscopic cracks[9]) is the more probable explanation. The nature of the intermediate mechanism (II) is still a matter of conjecture.

Of the three mechanisms of breakdown, only the thermal can be analyzed mathematically to a satisfactory extent. Several investigators have worked out the thermal theory for the resistivity law:

$$\rho = \rho_0 \epsilon^{-\gamma\theta}$$

but Fock[10] appears to be the only one who has used the more accurate but less tractable expression:

$$\rho = \rho_1 \epsilon^{\theta'/T}$$

Also the Fock theory seems to be the only one which gives exact values for all thicknesses and temperatures. Unfortunately, however, the results as given by Fock do not admit of easy visualization. They are given in the form of three tables, the breakdown voltage being obtained by using all three one after another. If his parameter c is assumed to be independent of x (which is true to engineering accuracy*), the results can be simplified to a single set of curves, Fig. 12. Here the two Fock parameters v and c are defined by the relations:

$$v = \frac{500\ V}{\sqrt{4.60 \rho_1 k_1 \beta}},$$

$$c = \frac{k_2}{k_1} \frac{d}{2\delta}.$$

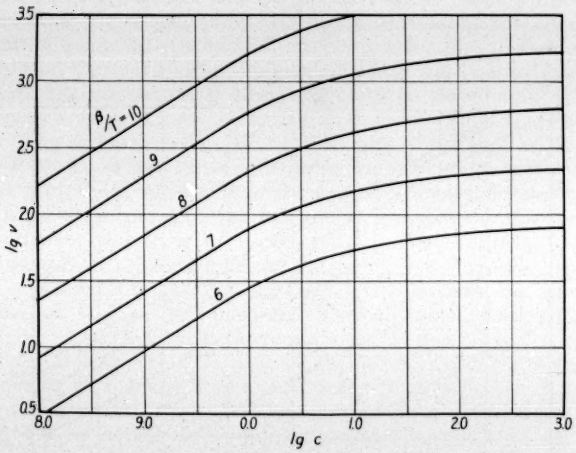
* Reference to Table 2 of Fock's paper shows that for $0 < \alpha < 12.5°$, c is changed by less than 0.01% by a variation of x through the range *12* to *22*; while even at $\alpha = 60°$, the change is only 2.4%.

k_1 = thermal conductivity of insulation, watts/cm./deg. Cent.
k_2 = thermal conductivity of electrodes,
d = thickness of insulation, cm.,
δ = " " electrodes, cm.,
V = breakdown kv.,

and β is obtained from the resistivity equation:

$$\rho = \rho_1(10)^{\beta/T}.$$

FIG. 12.



Breakdown Voltage according to the Fock thermal theory.

$$v = \frac{500\ V}{\sqrt{4.60\rho_1 k_1 \beta}}$$

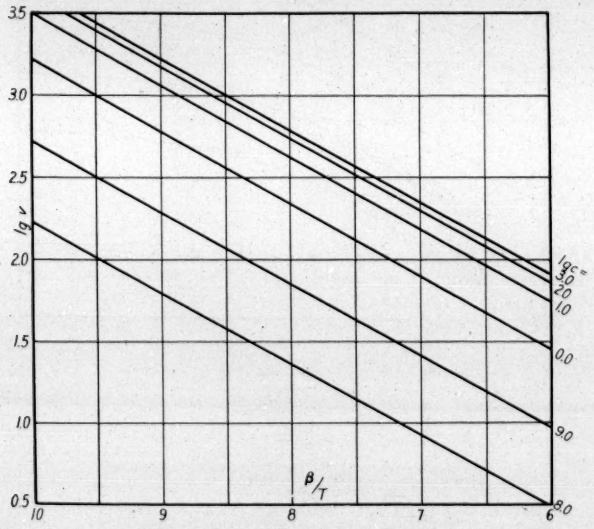
$$c = \frac{k_2}{k_1}\frac{d}{2\delta}$$

k_1 = thermal conductivity of insulation, watts/cm./deg. Cent.
k_2 = thermal conductivity of electrodes.
d = thickness of insulation, cm.
δ = thickness of electrode, cm.
$\rho = \rho_1(10)^{\beta/T}$

It will be noted that these curves give an excellent picture of the whole range of thermal breakdown. If resistivity, thermal conductivity, etc. are known, the breakdown voltage

can be predicted for any temperature and for any thickness, provided of course that the breakdown is thermal. With a given material and given electrodes, the breakdown kilovolts V and the thickness d are directly proportional to v and c, respectively. Thus the curves show that for small thicknesses ($lg\ c < 9.6$, approximately) the breakdown voltage varies exactly as the square root of the thickness, a conclusion which was enunciated previously by Rogowski, Kármán, and others. But the curves show more than this—they indicate that at greater thickness ($lg\ c > 9.6$) the breakdown voltage varies to less than the 0.5 power of the thickness and gradually approaches a constant value as the thickness is increased.

FIG. 13.



Breakdown Voltage according to the Fock thermal theory.

The effect of temperature is better shown by Fig. 13 which was obtained by replotting Fig. 12. To the limited accuracy

of the graph, these lines appear to be straight with a slope

$$b_3 = 0.435\,\beta.$$

Inge and Walther [2] have shown that the lines are not exactly straight, but are slightly concave upward, the slope at any point being

$$b_3 = \beta/2 - T/2.30.$$

The two expressions give values in reasonable agreement for ordinary ranges of temperature.

It is now desirable to compare the predictions of the Fock theory with the experimental results. Unfortunately, a precise quantitative check is not yet possible due to lack of data on thermal conductivities and temperature coefficients. With the present data, however, it can be stated that the results are in at least approximate agreement with the theory.

The curves of Fig. 12 explain why the slopes of the $lg\ V - lg\ d$ curves are not the same for the two glasses, and are both much smaller than the generally accepted value of 0.5. Due to the good thermal conductivity of the mercury electrodes and their excellent contact with the glass, the materials are operating on the flatter curve to the right, the G-1 glass being at approximately $lg\ c = 1.0$ and the lime glass at 1.14 for 100 microns. This difference can be explained by a reasonable difference in the thermal conductivity of the two glasses. Of course, this means that the straight lines of Figs. 5 and 7 should actually be slightly curved to conform to the theory. These curved lines would fit the data about as well as the present straight lines do.

In regard to the change with temperature, the experimental results are apparently straight lines as required by theory. The slopes are 1540, 1910, 1530 and 1500 for the various glasses as shown in the last column of Table IV. Division by 0.435 gives 3540, 4390, 3520 and 3440 for β. It is well known that for all glasses β lies in the range from 3000 to 5000, so the slopes b_3 are in at least approximate accord with theory.

CONCLUSIONS.

The results of these tests indicate that there are three distinct mechanisms of breakdown in the range of temperature

and thickness usually used. Which one will be encountered in a given case depends on temperature, thickness, and constants of the material.

In the disruptive range, breakdown gradient is independent of thickness, temperature, and resistivity. It is a constant of the material and is 3100 kv./cm. for G-1 glass.

In the intermediate range, the breakdown voltage varies approximately as the $\frac{2}{3}$ power of the thickness and is an exponential function of the reciprocal of the absolute temperature.

In the thermal range, the breakdown voltage varies as the half or lesser power of the thickness and is also an exponential function of the reciprocal of the absolute temperature.

Thus it is possible to tabulate the characteristics of the different regions for glass as follows:

Type.	Effect of Temperature.	Effect of Thickness.	Effect of Resistivity.	Effect of Therm. Cond.
I. *Disruptive* $V = K_1 d$	None	Directly proportional	None	None
II. *Intermediate* $V = K_2 d^{n_2} (10)^{b_2/T}$ $n_2 = 2/3$ approx.	Exponential	Varies as 2/3 power	Has marked effect	?
III. *Thermal* $V = K_3 d^{n_3} (10)^{b_3/T}$ $n_3 = 0.5$ or less $b_3 = 0.435\,\beta$ where β is obtained from $\rho = \rho_1 (10)^{\beta/T}$	Exponential	Varies as half power (or less)	Has marked effect	Has marked effect

In conclusion, the authors wish to express their sincere appreciation of the help and inspiration of Dr. V. Bush. They also wish to acknowledge their indebtedness to Messrs. R. A. Swan and W. F. Bartlett for the results on Pyrex and to Messrs. W. E. Creedon and W. E. Lowery for the tests on G-1 glass at − 60 deg.

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Dustless Ash Removal. (*Public Works*, November, 1929.) One of the great nuisances connected with ordinary methods of collecting and removing ashes in American municipalities is the dust caused by dumping the ashes into carts on windy days. This nuisance can be avoided in a number of ways, one of which would be to remove the ash barrel with its contents, replacing it with an empty barrel as is done in some cities in collecting garbage. This and other methods have not been practiced, chiefly because of the expense involved. But with the increasing demands of the American public for greater comfort and convenience in connection with municipal housekeeping, it is probable that this will be remedied before many years.

In New York City a method of avoiding ash dust has recently been tried out and put into service by a local company, using an equipment constructed especially for this purpose. This equipment consists of a truck containing a hopper into which the ashes are drawn by suction through a large tube; the hopper being inside of a large enclosed truck. The ashes in the hopper are then conveyed by a totally enclosed conveyor and discharged into an ordinary open truck.

The enclosed truck is equipped with a gas-electric drive, which furnishes power for operating the suction system and also the conveyor belt, as well as propelling the truck itself. The suction is created by a centrifugal compressor rated at 6,000 cu. ft. per minute at a speed of 3,500 revolutions per minute and driven by a 40 h.p. motor. The capacity of the equipment is a suction of 2,800 cu. ft. per minute, giving a velocity of 145 ft. per second in the intake pipe.

A permanent pipe line is installed in the building extending from the ash bin to the sidewalk, and the truck makes connection to this pipe by means of a pipe section attached to the truck and connected to the hopper, which section is lowered into place and tightly connected at the sidewalk with the permanent line. This equipment is designed for apartment houses and other large buildings, but it is proposed later to construct a smaller unit with a flexible pipe line which can be used for removing ashes from the cellars of residences without having to incur the expense of a permanently installed pipe line and vault under the sidewalk.

THE ACTION OF CHROMIC ACID ON THE SENSITIVITY OF SOLARIZED SILVER BROMIDE PLATES.*

BY

A. P. H. TRIVELLI AND R. P. LOVELAND.

INTRODUCTION.

J. M. Eder [1] gave the first explanation of the increase of sensitivity, by ripening, of the silver halide of photographic emulsions. According to his hypothesis, specks of reduced silver halide are formed on the surface of the silver halide grains during ripening. To produce developability of the silver halide grains which do not contain these specks, it is necessary that these grains absorb a certain amount of light. This amount of light can be diminished by a chemical reduction which forms sensitivity specks (Reifungsreduktionskeime). A smaller exposure is then required to add enough reduced silver halide to the speck until developability is produced. This explanation has been accepted almost generally and forms the basis of the concentration speck theory of the latent image [2] for which a photo-electric mechanism was suggested.[3] Eder's explanation was supported by Lüppo-Cramer [4] who found by means of experiments with chromic acid that a highly sensitive photographic plate shows a greater decrease in sensitivity after treatment with chromic acid than a plate of original low sensitivity. Very slow plates, such as silver bromide collodion plates, which are supposed to have no specks, do not change their sensitivity on treatment with chromic acid. Later Lüppo-Cramer [5] states that in his experiments he took into account the elimination of chromic acid from the gelatin before exposure and development.

* Communication No. 400 from the Kodak Research Laboratories.

[1] *Eder's Handbuch*, II, 1, 288 (1927).

[2] S. E. Sheppard, A. P. H. Trivelli, and R. P. Loveland, J. FRANK. INST., **200**: 51 (1925).

[3] A. P. H. Trivelli, J. FRANK. INST., **204**: 649 (1927); **205**: 111 (1928); *Nature*, **121**: 728 (1927).

[4] *Phot. Mitt.*, 328 (1909).

[5] *Eder's Handbuch*, II, 1, 288 (1927).

These experiments were not known to S. E. Sheppard, E. P. Wightman, and A. P. H. Trivelli [6] when they investigated the action of chromic acid on the sensitivity of photographic emulsions and, independently, worked out a method of eliminating the chromic acid. The results of their investigations were in agreement with the experiments of Lüppo-Cramer.

The first idea—that the action of chromic acid on the sensitivity is a simple oxidation of the sensitizing speck and only decreases gradually the sensitivity of the whole emulsion until the basic sensitivity of the silver halide is reached—was shown to be incomplete by the experiments of W. Clark.[7] The matter became still more complicated when one of us discovered, with a special experimental emulsion, that chromic acid is able to give at times an increase of sensitivity instead of a decrease. The plates were submitted to E. P. Wightman and S. E. Sheppard [8] of these Laboratories for further investigation.

In all this work, the exposure, after the treatment, was restricted to the first part of the H. and D. curve with the purpose of studying the action of chromic acid on the sensitivity specks. H. Arens [9] published the first quantitative investigations of the action on photographic plates which had been treated with chromic acid and then exposed to the solarization region. He obtained an increased density in the solarization region and an increased maximum density. Lüppo-Cramer [10] obtained quite different results. He prepared two emulsions in which the only difference was that one emulsion was precipitated with 80 grams of ammonium bromide and the other emulsion with 60 grams of ammonium bromide. All other conditions in the preparation of these emulsions were kept as much as possible the same. After the chromic acid treatment, the two emulsions showed great differences in the overexposure region. Both showed decrease of sensitivity over the entire exposure region. In one emulsion the characteristic curve shifted parallel to higher

[6] J. FRANK. INST., 653 and 779 (1923); *Trans. Farad. Soc.*, 19: 306 (1923).
[7] *Brit. J. Phot.*, 74: 227, 243 (1927).
[8] *Phot. J.*, 68: 201 (1928).
[9] *Z. physik. Chem.*, 114: 337 (1925).
[10] *Eder's Handbuch*, II, 1: 598 (1927).

log E values without changing the maximum density; the other showed an additional considerable decrease of the maximum density. Lüppo-Cramer explains the observed differences by the acceptable assumption that the silver halide grain of the photographic emulsion should have a different structure, depending on the precipitation conditions and the after-treatments during the manufacturing of the photographic emulsion. We may picture this as a difference in the distribution of inclusions or adhesions of foreign substances surrounded by the crystal lattice of the silver halide and we may also picture this as a difference in the distribution of the iodide content of the silver bromide grains. If a washed silver bromide precipitate is heated in a test tube with a chromic acid solution, the presence of bromine vapor above the solution is soon noticed. We would, therefore, expect in our experiments with the chromic acid treatment a slight action on the silver halide at the surface of the grains. This action may change the iodide content and it may change the surface of the grain—for example, making it rougher. It is, however, evident that here also the action of chromic acid is of a complex nature. The action on the iodide content can be eliminated by using only pure silver bromide in the photographic emulsion. Recently we obtained a still different effect, i.e., a photographic emulsion that after treatment with chromic acid showed a normal action in the first part of the H. and D. curve; it, also, if the exposure was made with light of high intensity and the time of development was less than 12 minutes at 17° C., showed in the solarized region of the curve some characteristics similar to those described by H. Arens. With longer time of development the maximum density shifted towards longer times of exposure. In the cases, with the chromic acid treatment, when we observed increase of sensitivity in the first part of the H. and D. curve it was always with photographic emulsions containing grains which were only slightly sensitized or which were insufficiently sensitized. In all cases, when the emulsions investigated contained grains sensitized almost to the saturation point, which is noticeable by the appearance of emulsion fog, the chromic acid treatment produced desensitization only. This holds for gelatin emulsions only; collodion emulsions were not investigated. As a

matter of fact the number of observations might have been too few to make such a general conclusion, but for the moment there does not seem to be anything to contradict these statements.

The increase of sensitivity by the chromic acid treatment seems to be possible if a new sensitivity is introduced by the action of chromic acid. The above mentioned investigation of E. P. Wightman and S. E. Sheppard showed that this newly produced sensitivity is again destroyed by prolonged treatment with chromic acid. They explained the action as the possible formation of a sensitizer by the chromic acid action on a special gelatin used for the manufacturing of these plates. This is in agreement with British Patent No. 259,926 of October, 1925, of the I. G. Farbenindustrie Akt.-Ges., which states that gelatin which has been hydrolyzed and simultaneously partially oxidized by acid after neutralization may give increased sensitivity to photographic emulsions.

The action of chromic acid on the sensitivity of photographic plates has, therefore, to be regarded as one of a complex nature:

(*a*) A reaction on the silver halide.

(*b*) A reaction on the sensitivity specks, which according to the investigations of S. E. Sheppard [11] contain silver sulfide and according to the investigations of E. P. Wightman and R. F. Quirk [12] and W. Clark [13] in all probability are composed of silver sulfide and metallic silver, adsorbed on the surface of the silver halide grains.

(*c*) An action which produces sensitivity by forming a sensitizer out of the gelatin. The nature of this sensitizing action is not yet known. (In this paper we will call this sensitizer the protein sensitizer.) * Prolonged action of chromic acid destroys this sensitivity.

It is evident that in our case this type of sensitivity never can be of a high degree, because the grains are fixed in the

[11] *Colloid Symposium Monograph*, 3: 76 (1925); *Phot. J.*, 65: 380 (1925).
[12] J. FRANK. INST., 731 (1927).
[13] *Brit. J. Phot.*, 74: 227 and 243 (1927).
* It may be similar to the action of thiocarbamides in forming silver sulfide specks from sulfur-containing proteins.

gelatin during the chromic acid treatment. Only the gelatin in the immediate surroundings of the grain is able to form the sensitizer, while in an emulsion stirred during ripening the grains are continuously moving and getting in contact with a much larger amount of gelatin, which produces higher sensitivity. If, before the chromic acid treatment, the original plate had a higher speed, it is very probable that this higher speed is due to silver sulfide-silver specks and not to the protein sensitizer, because in ordinary emulsion-making the reaction for the formation of the silver sulfide-silver speck has very likely a higher velocity than the formation and action fo the protein sensitizer by hydrolysis and partial oxidation. The greater the speed of a plate the greater in general will be its content of silver sulfide-silver. In this case it is difficult to detect the small increase in speed after the chromic acid treatment produced by the newly produced protein sensitizer. One phenomenon covers the other.

The action of chromic acid on the silver sulfide-silver speck is also of a complex nature. Its reaction velocity on silver is high; the reaction velocity on silver sulfide is very low.

If we try to picture all these reactions in a crude diagram we would represent it as in Fig. 1. Along the Y-axis are represented three different emulsion speeds: high, medium, and low. Suppose that the high-speed emulsion is sensitized

FIG. 1.

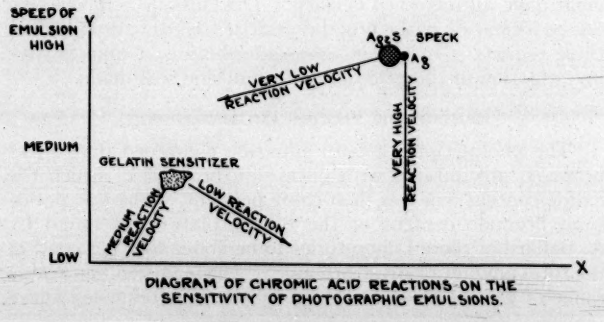


Diagram of the chromic acid reaction on the sensitivity specks of photographic emulsions.

only by silver sulfide-silver specks and that it contains these up to the saturation point, which means the sensitivity is so high that emulsion fog starts to appear. The action of the chromic acid on the silver of the specks, being of a high reaction velocity, will decrease the sensitivity very quickly while its component action on the silver sulfide of the specks, being of a low velocity, tends to decrease the sensitivity very slowly. This is in agreement with the quantitative investigations of W. Clark [14] on the chromic acid action on sensitivity. The arrows in the figure point toward the *X*-axis, which means decreased sensitivity.

The formation and the destruction of the protein sensitizer are of course to be regarded as always proceeding simultaneously so that the resultant sensitivity exhibits a low maximum during the acid treatment. The arrows indicate the decrease and increase in speed.

The photographic emulsion, mentioned above, showed the same phenomenon of decreased density as high-speed emulsions in the first part of the H. and D. curve before maximum density is reached, in spite of the fact that its speed has to be classified as a low medium one. These exposures were made with low light intensity. It seems that here the chromic acid reaction on the silver sulfide-silver specks was dominating over the reaction of the protein sensitizer. The maximum density region and the solarization region were exposed to high light intensity. In both regions the chromic acid treatment gave an increased density. The chromic acid reaction on the formation of the protein sensitizer seems to dominate in these regions. To obtain more information, a quantitative investigation of this photographic emulsion was made.

PHOTOGRAPHIC MATERIAL AND DEVELOPMENT.

The photographic gelatin emulsion contained pure silver bromide, precipitated with potassium bromide of which the iodide content was less than 0.002 per cent. The free potassium bromide content of the coated plates was found by A. Ballard of these Laboratories to be about 0.03 per cent. of the total amount of silver bromide. The emulsion has a wide range of grain sizes as is shown by the size-frequency curve

[14] *Phot. J.*, 64: 91 (1924).

published by one of us in a previous investigation on the Herschel effect.[15] Development was effected in a bath at 17° C. controlled by a thermostat with brush [16] in pyro-soda according to the formula:

Pyro (M/20)	6.304	grams
Sodium sulfite (anhyd.)	25	"
Sodium carbonate	21.2	"
Potassium bromide (M/100)	1.19	"
Water to make	1	liter

With 4 minutes' development at 68° F. (exposure made to acetylene light, screened to daylight with No. 79 Wratten filter), a sensitometric test showed a speed of 63 H. and D.; gamma, 1.12; and fog, 0.07. Since little is known about the development of plates treated with chromic acid and exposed afterwards in the region of the characteristic curve where solarization occurs, many observations were collected. At every interval of development, 5 strips were made and the average density was plotted. The strips were developed 1, 2, 3, 4, 5, 6, 7, 8, 10, 12, 16, 22, 27, and 32 minutes at 17° C. The sulfur dioxide content of the sodium sulfite was determined analytically and the actual amount calculated for an equivalent of 100 per cent. pure salt. Development was stopped at the required time with dilute acetic acid (1 per cent.); the plates were fixed in an acid fixing bath. Densities were read on a Martens densitometer which had been carefully checked with a Jones densitometer.[17] This made it possible to compare the densities which were obtained.

THE SENSITOMETER.

The exposures were made with a non-intermittent sensitometer of 26 steps $\sqrt{2}$ ratio exposure. The light intensity was kept constant and the time of exposure was varied. The maximum time of exposure was 5791 seconds. The light source was a 500-candle power standard monoplane tungsten filament lamp, operated at 104.8 volts to give a color temperature of 2700° K.

On account of the many and the long exposures it was

[15] J. FRANK. INST., 207: 765 (1929).
[16] *Cf.* W. Clark, *Phot. J.*, 65: 76 (1925).
[17] *J. Opt. Soc. Amer.*, 7: 230 (1923).

necessary to keep the light intensity as constant as possible. For this purpose a voltage regulator, which maintained voltage constant to within one volt, was designed by A. L. Schoen of these Laboratories. A record of the voltage changes is shown in the above mentioned publication of the Herschel effect. In this work the observed deviations correspond with less than 6 per cent. intensity differences in the actinic part of the spectrum. No filters were used. The photographic plates were exposed to the range of the characteristic curve in two separate segments. The last step of the first segment, including from the toe to the maximum density, received 353.79 m.c.s. exposure; the second segment commenced with a first step of 495.71 m.c.s. exposure, making a close continuation of sequence of exposures. There was a diaphragm at a distance of 99 cms. from the photographic plates. For the first segment the aperture produced an optical intensity of 0.055 m.c. on the plate; for the "overexposed" segment the intensity was 444.66 m.c. This great difference of light intensity produced a failure of the reciprocity law * so that a continuous curve could not be drawn for the entire range because of the marked difference in density of the two adjacent ends of the curves.

TREATMENT OF DATA.

Errors in exposures and in density readings are negligible compared with errors in development. The sensitometric determinations are in general sufficiently reliable to determine the shape of the curve, but smoother results are obtainable. The gamma of the curve for time of development was corrected by a method of smoothing suggested by L. A. Jones. Values from the H. and D. curves were plotted as functions of development time; the smoothed values from the density-time curves were then replotted as H. and D. curves. This may be repeated. The results obtained show that up to about 10 minutes' development, the smooth curves are very reliable and represent the real data as nearly as it is possible under these circumstances. Beyond 10 minutes' development differences in thickness of the emulsion so influence the densities that the deviations in densities increase and the averaging becomes less accurate.

* This emulsion was investigated for reciprocity failure by V. C. Hall and A. P. H. Trivelli (J. FRANK. INST., 207: (1929)) and found to have abnormal gamma curves with varying light intensity.

Attempts were made to apply fog correction based on the Meidinger-Wilsey formula.[18] In this method it is necessary to know the maximum density (D_∞) at infinite development time. Wilsey's method uses the value of D_∞ calculated by Nietz' development function:

$$D = D_\infty(1 - e^{-k \log \frac{t}{t_0}}).$$

Inasmuch as none of the data were fitted by this equation this method could not be used, but D_∞ was taken as the maximum density at 32 minutes' development from the D–t curves, which appeared justified by their nearly horizontal course. The Meidinger-Wilsey correction was then applied (fog was everywhere below 0.5). It is probably incorrect for inherent emulsion fog and still more so where a specific fogging action of the desensitizers and developers supervene, but the fog corrections were not so large as to vitiate the general results.

THE CHROMIC ACID TREATMENT.

The chromic acid treatment was given in accord with the latest investigations of E. P. Wightman. All manipulations were made at 15° C. First the plates were treated for 30 minutes in a water solution of 0.5 per cent. chromic acid and 0.2 per cent. sulfuric acid, followed by 5 minutes' rinsing in tap water. After that the plates were bathed for 5 minutes in a 1 per cent sodium bicarbonate solution. Then they were treated again for 15 minutes in another fresh 1 per cent. sodium bicarbonate solution. Finally the plates were washed for 30 minutes in running tap water and dried in a drying cabinet at 4° C. Constant care was taken that the time of exposure and development after the chromic acid treatment was kept the same and did not extend beyond 24 hours.

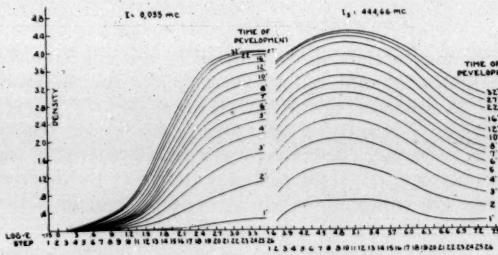
EXPRESSION OF RESULTS.

In Fig. 2 are given the H. and D. curves for the low-intensity (I = 0.055 m.c.) and for the high-intensity (I = 444.66 m.c.) exposures for different times of development. In Fig. 3 are given the density-time development (D–t) curves

[18] *Phot. J.*, **65**: 454 (1925). *Cf.* also R. B. Wilsey and H. A. Pritchard, *J. Opt. Soc. Amer.*, **12**: 661 (1926); H. A. Pritchard, *Phot. J.*, **67**: 447 (1927); S. E. Sheppard, *Phot. J.*, **66**: 399 and 470 (1926).

plotted from the data of Fig. 2. The curves of high-intensity exposures had to be separated into two groups, one for each side of the H. and D. maximum, to avoid interference with one another.

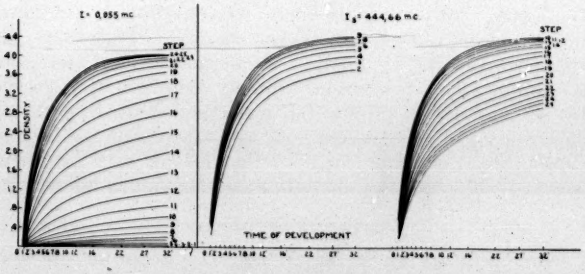
FIG. 2.



H. and D. curves for a pure silver bromide emulsion extended to the first reversal of the solarization region.

H. Scheffers [19] states that it is well known that on development of solarized pictures a very thin negative first appears, which later reverses into a positive. According to his

FIG. 3.



D-t curves for the same emulsion with the same exposures as Fig. 2.

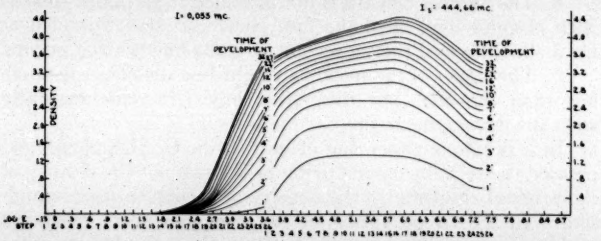
curves this reversal should take place under the conditions of his experiments, between 3-minute and 4-minute development time. We believe that those curves, in which the rate of

[19] *Z. Physik*, **20**: 109 (1923).

development of only two steps are compared, are insufficient for such a conclusion. The reversal during development is determined by the change of gamma from a positive to a negative value. Our curves did not show the slightest indication of such a change. On the contrary we observed from the beginning to about 16 minutes' development an increasing negative gamma and later on a decreasing negative gamma finally approaching zero with very long time of development. We have also observed similar effects upon many other photographic plates and films and we have been unable to detect any change in the sign of gamma before 32-minutes' development. We regard, therefore, the observations on the changing of negatives into positives during development in the region of solarization as an illusion.

In Fig. 4 are given the H. and D. curves of the same emul-

FIG. 4.



H. and D. curves for the same emulsion treated with chromic acid extended to the first reversal of the solarization region.

sion treated with chromic acid and with the exposures extended to the solarization region. In Fig. 5 are given the *D–t* curves plotted from the data of Fig. 4.

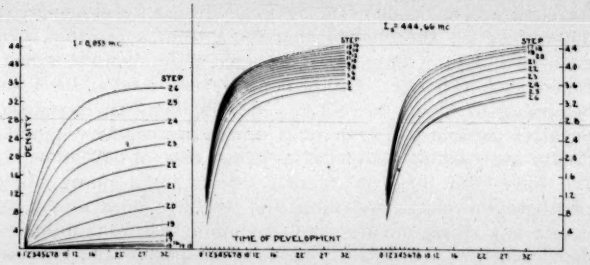
Comparing all these curves, we find the following facts:

1. The chief effect of the chromic acid treatment on the first segment is to reduce speed, i.e., to push the curves to the right.

2. The shape is also changed in the second segment.

3. The same maximum density with maximum development is produced with or without chromic acid pretreatment. The latter merely shifts it to the right. This shift is apparently not the same as the shift in speed, or even sensitivity.

FIG. 5.



D–t curves for the same emulsion with the same exposures as Fig. 4.

4. At shorter development times the effect is to increase maximum density.

5. The highest density is not obtained from plates treated with chromic acid until the first curve has been rounded as for a shoulder and then a second straight-line portion occurs.

6. The slopes of the second straight-line portions are much less than the first, but they (the slopes) increase regularly with the development time.

In a previous paper one of us with S. E. Sheppard [20] expressed the relative desensitizing as the ratio of the density of the original emulsion to the density of the desensitized emulsion. In the investigation of the Herschel effect a similar problem arose, namely, to find a quantitative expression for the change in density. There it was later found that it is better to express the decrease in density by the percentage formula:

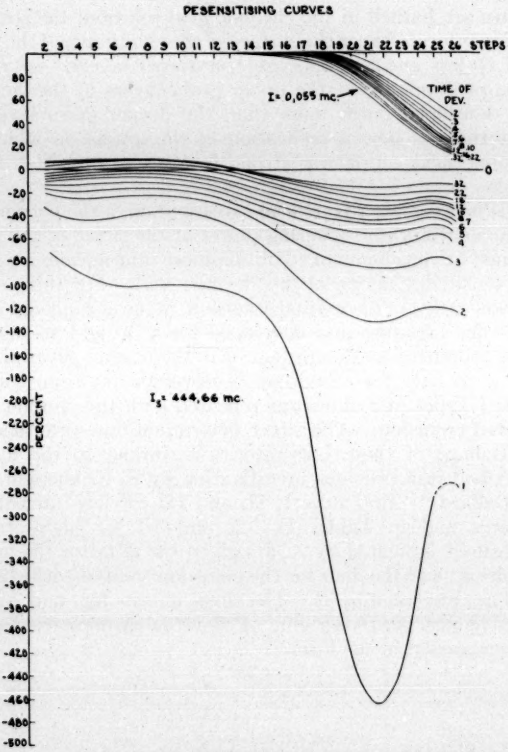
$$100\left(\frac{D - D_{des}}{D}\right).$$

This formula applied to the desensitizing with chromic acid gives the curves of Fig. 6. The two groups of curves are here given one above the other on the same Y-axis as percentage scale. It can be seen that with high intensity exposures desensitizing takes place only in that part where the time of development is long and the gamma of the curves is positive.

[20] *Phot. J.*, **66**: 505 (1926).

At maximum density the desensitizing is negative, which means that the density increases after the chromic acid treatment. This increase continues and reaches a maximum at the inflection point of the solarized part of the curves and, after a

FIG. 6.



Desensitizing curves.

decrease, shows the beginning towards a second maximum. The first maximum is extremely high with short time of

development. With 1-minute development a maximum increase of density of about 470 per cent. was observed at the inflection point of the solarized curve. The effect of the chromic acid treatment on the short-time developed strips is much more pronounced than on longer-time developed strips. This is obvious if we consider the treatment itself. When the plates are bathed in the chromic acid solution, the strongest action is located near the surface of the emulsion and the action will be less and less noticeable in deeper layers. In a short time of development the upper grain layers in the emulsion are developed much more than the deeper grain layers, so that there is now a separation of the grains on which the chromic acid action was strong from those on which it was weak.

It is necessary to make an investigation of the photometric equivalent and the covering power of the silver of the grains formed by development to obtain more information regarding the sensitizing action of the chromic acid. For this purpose density strips of the normal emulsion, made at high and at low intensity exposure and developed for 3, 8, and 16 minutes, were submitted for determination of the mass of silver present, one strip only for each time of development from each intensity exposure. This was repeated with the chromic acid-treated emulsion. The silver determinations were made by A. Ballard of these Laboratories according to the method described in a previous investigation by S. E. Sheppard and A. Ballard.[21] In Tables I, II, and III for low-intensity exposures and in Tables IV, V, and VI for high-intensity exposures, indicated by A, are given the data for the normal emulsion; and the data for the emulsion treated with chromic acid are indicated by B. The silver masses Ag_A and Ag_B are given in mgs. per 100 sq. cm. $P.E.$ is the photometric equivalent expressed in the form:

$$P.E. = \frac{S}{D},$$

where S = the mass of silver per cm.^{2} and
D = the density.

[21] J. FRANK. INST., 206: 659 (1928).

TABLE I.

I = 0.055 m.c. 3′ dev.

Step.	Log E.	Dens. A.	Dens. B.	Ag_A.	Ag_B.	$P.E.\ 10^3$ A.	$P.E.\ 10^3$ B.	$C.P.\ 10$ A.	$C.P.\ 10$ B.	$Ag/E.\ 10^7$ A.	$Ag/E.\ 10^7$ B.	Remarks.
26	3.60	1.11	1.56	16.7	33.4	150	214	66.67	86.73	47.2	94.4	
25	3.45	0.86	1.21	13.7	24.6	160	203	62.50	49.26	54.8	98.3	
24	3.30	0.66	0.93	11.5	25.7	175	274	57.14	36.50	65.0	145.3	
23	3.15	0.51	0.70	8.76	18.9	172	270	58.14	37.04	70.0	151.1	
22	3.00	0.38	0.52	5.75	12.6	152	242	65.79	41.32	65.0	142.5	
21	2.85	0.23	0.31	4.40	8.77	191	283	52.36	35.34	70.4	140.2	
20	2.70	0.12	0.19	3.00	—	250	—	40.00	—	67.8	—	B lost
19	2.55	0.06	0.09	1.92	2.46	320	373	31.25	36.63	61.4	186.6	
18	2.40	0.04	0.05	1.37	2.37	342	476	29.24	21.01	61.9	107.1	

TABLE II.

I = 0.055 m.c. 8′ dev.

Step.	Log E.	Dens. A.	Dens. B.	Ag_A.	Ag_B.	$P.E.\ 10^3$ A.	$P.E.\ 10^3$ B.	$C.P.\ 10$ A.	$C.P.\ 10$ B.	$Ag/E.\ 10^7$ A.	$Ag/E.\ 10^7$ B.	Remarks.
26	3.60	2.11	2.13	47.7	—	226	—	44.20	—	134.8	—	B—off color
25	3.45	1.96	1.89	43.3	45.7	221	242	45.15	41.32	173.1	182.7	
24	3.30	1.61	1.60	36.7	41.1	228	256	43.86	39.06	207.5	232.3	
23	3.15	1.34	1.27	31.8	31.5	237	248	42.19	40.32	254.2	251.8	
22	3.00	1.08	.98	29.3	24.4	271	249	36.90	40.16	331.3	275.9	
21	2.85	.77	.64	23.3	16.0	303	250	33.00	40.00	372.6	255.9	
20	2.70	.49	.40	12.3	10.7	281	268	35.59	37.31	278.1	241.9	
19	2.55	.25	.26	6.30	7.67	252	295	39.68	33.90	201.4	245.3	
18	2.40	.09	.18	2.47	6.85	275	3.81	36.36	26.25	111.7	309.7	
17	2.25	.04	.15	1.64	6.00	410	4.00	24.39	25.00	104.9	383.6	

TABLE III.

I = 0.055 m.c. 16′ dev.

Step.	Log E.	Dens. A.	Dens. B.	Ag_A.	Ag_B.	$P.E.\ 10^3$ A.	$P.E.\ 10^3$ B.	$C.P.\ 10$ A.	$C.P.\ 10$ B.	$Ag/E.\ 10^7$ A.	$Ag/E.\ 10^7$ B.	Remarks.
26	3.60	3.18	3.29	80.2	80.6	252	245	39.68	40.82	226.7	227.8	
25	3.45	3.14	2.87	70.2	83.8	223	292	44.84	34.25	280.6	335.0	
24	3.30	2.41	2.34	58.4	63.0	242	269	41.32	37.18	330.1	356.2	
23	3.15	1.86	1.73	—	46.0	—	266	—	37.59	—	367.8	A lost
22	3.00	1.52	1.34	43.8	36.4	288	272	34.72	36.77	495.2	411.6	
21	2.85	1.21	.95	31.2	28.8	258	303	38.75	33.00	498.9	460.5	
20	2.70	.87	.62	21.6	17.2	248	278	40.32	35.97	488.4	388.9	
19	2.55	.64	.42	17.0	10.4	265	250	37.74	40.00	543.6	332.6	
18	2.40	.50	.30	12.3	7.4	248	247	40.32	40.49	556.2	334.6	
17	2.25	.44	.26	10.0	6.3	227	242	44.05	41.32	639.4	402.8	
16	2.10	.42	.23	9.6	5.75	229	250	43.67	40.00	868.2	520.0	

TABLE IV.

I_s = 444.66 m.c. 3′ dev.

Step.	Log*E*.	Dens. *A*.	Dens. *B*.	Ag_A.	Ag_B.	*P.E.* 10^2 *A*.	*P.E.* 10^2 *B*.	*C.P.* 10 *A*.	*C.P.* 10 *B*.	Ag/*E.* 10^6 *A*.	Ag/*E.* 10^6 *B*.	Remarks.
26	3.60	0.82	1.23	20.6	15.6	251	127	39.84	78.74	0.72	0.54	
25	3.45	.84	1.25	20.8	17.8	248	142	39.32	70.72	1.02	0.87	
24	3.30	.86	1.36	24.4	19.7	280	145	35.71	68.97	1.70	1.37	
23	3.15	.92	1.54	24.7	26.0	268	169	37.31	59.17	2.43	2.56	
22	3.00	.94	1.68	25.5	27.7	271	165	36.90	60.61	3.55	3.86	
21	2.85	1.02	1.99	23.0	31.8	225	160	44.44	62.50	4.53	6.27	
20	2.70	1.13	2.06	17.0	32.3	150	157	66.66	63.59	4.73	9.00	
19	2.55	1.20	2.19	22.2	34.0	185	155	54.05	64.52	8.75	13.4	
18	2.40	1.34	2.27	20.6	35.9	154	158	64.93	63.29	11.5	20.0	
17	2.25	1.43	2.27	20.6	36.2	144	159	69.44	62.89	16.2	28.5	
16	2.10	1.60	2.33	20.7	37.3	129	160	77.52	62.50	23.1	41.6	
15	1.95	1.63	2.33	—	33.4	—	143	—	69.93	—	52.6	*A* lost
14	1.80	1.70	2.33	—	32.9	—	141	—	70.92	—	73.3	*A* lost
13	1.65	1.80	2.33	20.0	32.9	111	141	90.09	70.92	63.0	103.7	
12	1.50	1.80	2.33	20.0	32.3	111	139	90.09	71.94	89.1	143.8	
11	1.35	1.82	2.33	17.1	32.9	94	141	106.38	70.92	107.8	207.4	
10	1.20	1.82	2.33	15.3	32.3	84	139	119.05	71.94	136.5	288.3	
9	1.05	1.82	2.33	—	32.9	—	141	—	70.92	—	414.8	*A* lost
8	.90	1.78	2.33	14.0	33.4	79	143	126.58	69.93	249.9	596.2	
7	.75	1.78	2.27	13.2	32.9	74	145	135.14	68.97	328.7	819.3	
6	.60	1.78	2.25	11.9	32.9	67	146	149.25	68.49	421.1	1164.6	
5	.45	1.75	2.19	—	35.9	—	164	—	60.98	—	1810.5	*A* lost
4	.30	1.70	2.07	15.1	33.2	89	160	112.36	62.50	1087.9	2391.9	
3	.15	1.60	1.70	15.1	26.0	94	153	106.38	65.36	1523.0	2622.5	
2	.00	1.51	1.15	17.3	20.0	115	170	86.96	57.47	2492.8	2881.8	

TABLE V.

I_s = 444.66 m.c. 8′ dev.

Step.	Log *E.*	Dens. *A.*	Dens. *B.*	Ag_A.	Ag_B.	*P.E.* 10^3 *A.*	*P.E.* 10^3 *B.*	*C.P.* 10 *A.*	*C.P.* 10 *B.*	Ag/*E.* 10^6 *A.*	Ag/*E.* 10 *B.*	Remarks.
26	3.60	1.56	1.96	51.0	33.4	327	170	30.58	58.82	1.77	1.16	
25	3.45	1.56	1.96	54.8	36.2	351	185	28.49	54.05	2.26	1.78	
24	3.30	1.60	2.16	60.3	41.4	377	192	26.53	52.08	4.20	2.88	
23	3.15	1.66	2.35	61.4	41.1	370	175	27.03	57.14	6.05	4.05	
22	3.00	1.75	2.66	59.7	40.6	341	153	29.33	65.36	8.31	5.68	
21	2.85	1.83	2.94	62.5	44.1	342	150	29.24	66.67	12.3	8.69	
20	2.70	2.16	3.22	60.8	53.4	281	166	35.59	60.24	16.9	14.9	
19	2.55	2.33	3.52	63.0	58.9	270	167	37.04	59.88	24.8	23.2	
18	2.40	2.44	3.68	58.1	60.6	240	165	41.67	60.61	32.4	33.8	
17	2.25	2.68	3.83	58.6	58.1	205	152	48.78	65.79	46.2	45.8	
16	2.10	2.82	3.87	60.6	61.6	215	159	46.51	62.89	67.5	68.6	
15	1.95	2.97	3.87	52.6	59.2	177	153	56.50	65.36	82.9	93.3	
14	1.80	3.15	2.87	53.4	62.7	170	162	58.82	61.73	119.0	139.8	
13	1.65	3.33	3.87	49.3	62.7	148	162	67.57	61.73	155.4	197.6	
12	1.50	3.45	3.87	52.6	64.4	153	166	65.36	60.24	234.2	286.8	
11	1.35	3.53	3.80	52.6	64.6	149	170	67.11	58.82	331.6	407.2	
10	1.20	3.59	3.70	49.3	66.3	137	179	72.99	55.87	440.1	590.2	
9	1.05	3.62	3.65	45.2	64.6	125	177	80.00	56.50	570.0	814.5	
8	0.90	3.59	3.55	44.4	51.8	124	146	80.65	68.49	792.6	924.8	
7	0.75	3.52	3.48	42.2	60.3	120	173	83.33	57.80	1051.0	1501.7	
6	0.60	3.45	3.37	36.7	54.8	106	163	94.34	61.35	1298.8	1939.4	
5	0.45	3.40	3.25	34.5	55.1	101	170	99.01	58.82	1739.9	2778.8	
4	0.30	3.25	3.15	33.2	51.8	102	164	98.04	60.98	2391.9	3731.9	
3	0.15	3.03	3.01	32.6	51.8	108	172	92.59	58.14	3288.2	5224.7	
2	0.00	3.01	2.70	30.4	59.2	101	219	99.01	45.66	4380.0	8530.2	

TABLE VI.

I_s = 444.66 m.c. 16′ dev.

Step.	Log E.	Dens. A.	Dens. B.	Ag_A.	Ag_B.	$P.E.\ 10^3$ A.	$P.E.\ 10^3$ B.	$C.P.\ 10$ A.	$C.P.\ 10$ B.	$Ag/E.\ 10^6$ A.	$Ag/E.\ 10^6$ B.	Remarks.
26	3.60	2.09	3.15	78.4	70.1	375	223	26.67	44.84	2.73	2.44	
25	3.45	2.16	3.18	83.3	65.2	386	205	25.91	48.78	4.10	3.21	
24	3.30	2.37	3.38	86.6	68.0	365	201	27.40	49.75	6.03	4.74	
23	3.15	2.40	3.61	90.7	71.8	378	199	26.45	50.25	8.94	7.07	
22	3.00	2.60	3.76	87.4	77.3	336	206	29.76	48.54	12.2	10.8	
21	2.85	2.72	4.00	86.9	89.3	319	224	31.35	44.64	17.1	17.6	
20	2.70	2.92	4.08	86.9	88.8	298	216	33.56	46.30	24.2	24.7	
19	2.55	3.17	4.18	88.8	91.0	280	218	35.71	45.87	34.9	35.9	
18	2.40	3.30	4.18	75.1	92.6	228	222	43.85	45.05	41.9	51.6	
17	2.25	3.56	4.18	81.4	98.9	229	237	43.67	42.19	64.1	77.9	
16	2.10	3.80	4.15	75.1	97.3	198	240	50.51	41.67	83.7	108.4	
15	1.95	3.95	4.10	80.0	92.9	203	227	49.26	44.05	126.0	146.4	
14	1.80	4.00	3.99	80 6	96.2	202	241	49.51	41.49	179.7	214.4	
13	1.65	4.05	3.99	76.4	98.9	189	248	52.91	40.32	240.9	311.7	
12	1.50	4.10	3.99	75.4	97.3	184	244	54.35	40.98	335.8	433.3	
11	1.35	4.18	3.90	75.1	101.7	180	261	55.56	38.31	473.4	641.1	
10	1.20	4.24	3.90	64.7	80.0	153	205	65.36	48.78	577.5	714.1	
9	1.05	4.24	3.90	60.8	76.5	143	196	69.93	51.02	766.6	964.5	
8	.90	4.24	3.85	61.4	77.8	145	202	68.97	49.51	1096.1	1369.3	
7	.75	4.24	3.85	55.3	64.7	130	168	76.92	59.52	1377.2	1611.3	
6	.60	4.24	3.63	51.8	83.3	122	229	81.97	43.67	1833.2	2948.1	
5	.45	4.24	3.62	53.4	77.6	126	221	79.37	45.25	2693.1	3913.5	
4	.30	4.24	3.62	52.6	75.4	125	209	80.00	47.85	3789.6	5432.2	
3	.15	4.24	3.62	49.6	76.4	117	211	85.47	47.39	5002.8	7705.9	
2	.00	4.08	3.45	42.7	70.1	105	203	95.24	49.26	6152.7	10100.8	

The covering power $C.P. = \frac{1}{P.E.}$,

expressing the density per unit weight of silver.

By comparing the covering powers given in Tables I and II of the normal and of the treated emulsion we notice an increase of covering power with increased exposures. This means that with increased exposures smaller grains have been developed. The data for different times of exposure for the normal and for the treated emulsions are about parallel. In Table III the covering powers of the normal and of the treated emulsion have reached a constant value for different exposures. This means that the photometric equivalent at 16 minutes' development has become a photometric constant for the normal and for the treated emulsion of nearly the same value.

If we take the averages of the covering powers for different exposures we obtain with different times of development the following data, which give an approximate indication of the general relationship.

Time of Dev.	$C.P._A$	$C.P._B$	Δ
3 min.....	49.74	36.65	13.09
8 "	39.36	36.89	2.47
16 "	39.64	38.98	0.98

This shows that in general the covering power of the normal emulsion *A* is higher than the covering power of the treated emulsion *B*, which means that in the normal emulsion a greater number of smaller grains are developed than in the treated emulsion. This difference disappears with increasing time of development.

In a previous investigation by S. E. Sheppard, E. P. Wightman, and one of us [22] and by W. Clark [23] it was shown that in a very sensitive emulsion a treatment with chromic acid affected the larger grains more than the smaller grains. This would give an increased covering power. Here we find just the opposite. In spite of the fact, therefore, that the H. and D. curves show a normal action for the treated emulsion at low intensity exposures, the investigation shows

[22] *Trans. Farad. Soc.*, **19**: 309 (1923); J. FRANK. INST., **196**: 653 and 779 (1923).
[23] *Phot. J.*, **64**: 91 (1924).

an abnormal action of the covering power. The larger grains do not decrease their sensitivity so much as the smaller grains. The diagram in Fig. 1 may give an explanation. During the low light intensity exposures an increase of sensitivity by one of the hydrolyzing products of gelatin started to act, increasing the sensitivity of the larger grains more than the sensitivity of the smaller grains. This counteracted the greater decrease of sensitivity of the silver sulfide-silver specks on the larger grains by the chromic acid treatment.

In Tables IV, V, and VI are given the corresponding data for the high intensity exposures, giving the shoulder, the maximum density, and the first reversal of the solarization of the H. and D. curves.

In a paper on solarization, H. Scheffer [24] published the first experimental results on the silver determination in the solarized region. He found a fairly good constancy for the photometric equivalent over a range of densities from 0.08 to the solarized density of 1.12, which includes the maximum density at 1.64.

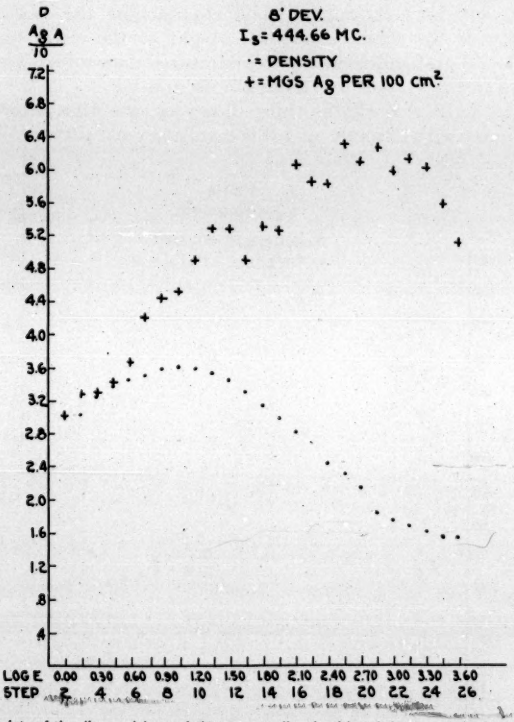
If we compare in Table IV for the normal emulsion *A* the weight of silver with the density, we see that the density diminishes with increased exposure, while at the same time the weight of silver increases till about step 22. In Table V these data are more pronounced. They are plotted in Fig. 7. The maximum silver weight is from step 18 to step 20. In Table VI these data are still much more pronounced. The maximum silver weight is from step 18 to step 23. We may say, therefore, that the maximum silver weight with increasing time of development stays at about the same exposure with a tendency to flatten out over a greater range of exposures with increasing time of development.

This is quite different from what H. Scheffer found. A decreasing density with a simultaneous increasing weight of silver means an increase of compactness of the developed silver grain. In ordinary exposures the silver grain is of a spongy nature if chemically developed. In extreme cases it has a volume slightly less than the original silver halide grain. In the majority of cases it has a volume larger than the original silver halide grain, in general increasing its projective

[24] *Z. Physik*, 20: 120 (1923).

area with the reduction potential of the developer. The structure of the silver grain, therefore, determines the difference in size between the projective areas of the original silver

FIG. 7.



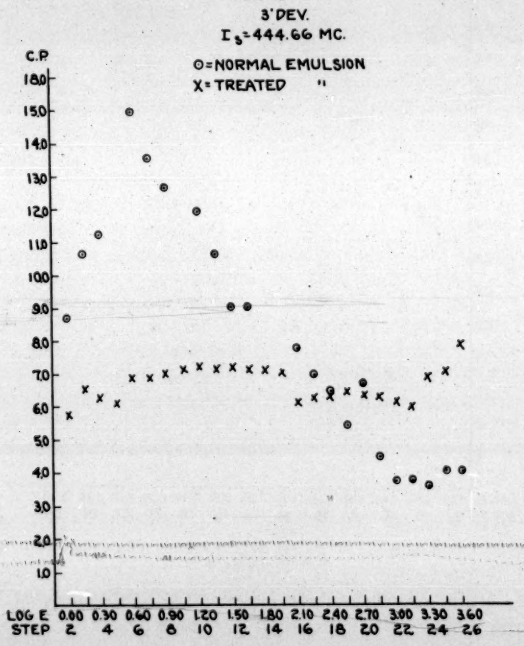
Plotted data of the silver weights and the corresponding densities of the normal emulsion in the overexposure region.

halide grain and the silver grain. The differences of the covering power of developed silver halide grains of the same shape and size with different developers are due to differences in the structure of the silver grains. In the above mentioned

case we notice an increasing difference among the decreasing density and the increasing silver weights with time of development for 3, 8, and 16 minutes. This in itself would be an explanation for the first reversal of the solarization if it were a general phenomenon, but it is found only in this special case. With very long exposures, when approaching the minimum density of the solarization, the weight of the silver of the developed grains decreased with increased exposure. This is shown in Fig. 7, and in Tables IV, V, and VI.

The most remarkable thing, however, was that after the treatment with chromic acid this emulsion gave silver weights

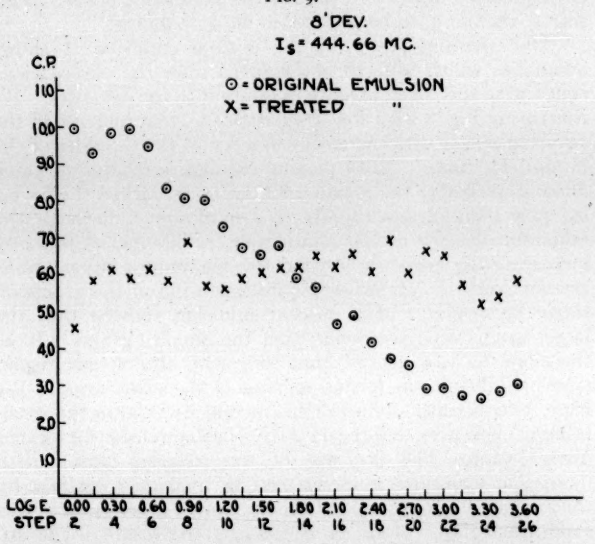
FIG. 8.



Plotted data of the covering power of the normal and of the treated emulsion in the overexposure region for 3-minute development.

which were approximately proportional to the density, which means a constancy of the photometric equivalent. In Figs. 8 and 9 are given the covering powers for 3 and 8 minutes'

FIG. 9.



Plotted data of the covering power of the normal and of the treated emulsion in the overexposure region for 8-minute development.

development. With 16 minutes' development the diagram differs very little from that of the 8 minutes' development.

By comparison with Table VI, it is seen that for the three development times the covering powers of the treated emulsion remain fairly constant with different exposures. The average value decreases with increasing time of development, which indicates that larger grains become developed through the entire range of exposures. The same effect occurs with the normal emulsion *A* as is shown in Figs. 8 and 9 and in Tables IV, V, and VI. Both plates in this exposure region act in a manner similar to their action in the first part of the

H. and D. curve. In the underexposed region of the H. and D. curve, both plates are similar in action. In their investigation on the covering power mentioned previously, S. E. Sheppard and A. E. Ballard found that this was true for two different emulsions in the first part of the H. and D. curve. This seems, therefore, to be general, in all probability.

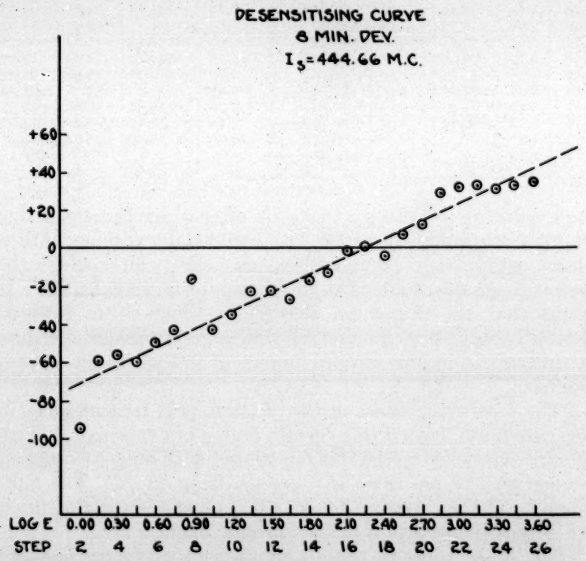
The covering power of the normal emulsion *A* shows anomalies which were to be expected after the observations concerning the silver weights in relation to the densities. By comparing Fig. 8 with Fig. 2 we notice a great increase in the covering power with increasing density at the shoulder of the H. and D. curve. After passing through a maximum value a few steps before the maximum density is reached the covering power diminishes rapidly to a minimum value near the minimum density of the solarization. This means that, by increasing the exposure beyond the maximum, larger grains are developed. A microscopic investigation of the grains on single layer plates of a process emulsion showed that the larger grains solarize sooner than the smaller grains. It is, therefore, to be expected, that they will, also, sooner regain developability in the second reversal of the solarization. We have several times obtained this second reversal in the sensitometer exposures, and the data have been put aside for further investigation. The decrease of the covering power with increasing exposure, however, can be explained entirely by the increased compactness of the developed silver grain in this exposure region. It is not necessarily the result of the appearance of renewed developable larger grains before the minimum density of the solarization is reached.

With such differences in the covering power of the developed grains of the normal emulsion *A* and of the treated emulsion *B*, the data for the high light intensity exposures given in Fig. 6 offer no evidence for a direct conclusion. The data for the covering power in the low light intensity exposure of the normal and of the treated emulsion justify the reliability of the curves for the first part of the H. and D. curve drawn in Fig. 6. For the overexposed part, the comparison has to be made in terms of mass of silver instead of densities. The data are given in Table VII. The determinations were obtained by Mr. A. Ballard for a development time of 8 minutes. These

data are indicated in Fig. 10. It is easy to see that the shape of the curve is quite different from those plotted in Fig. 6, since it approaches a straight line, which is drawn in the figure as a dotted line.

As shown in Fig. 6 there is, in the first part of the H. and D. curve, a continuous decrease in the desensitizing action of the chromic acid treatment with increase of exposure, approaching a zero point at a certain exposure. At this exposure the photographic emulsion does not change its sensitivity by the chromic acid treatment. In the overexposure region the lowest exposure starts with an increased sensitivity at a development time of 8 minutes. If we plot, as ordinates, log E on the basis of m.c.s., as it is done in Figs. 2 and 4, we get a connection between the curve of Fig. 10 and the 8-minute

FIG. 10.



Plotted desensitizing data from the silver weights in the overexposure region for 8-minute development.

development desensitizing curve of Fig. 6 for low-light intensity exposures, provided the differences, caused by the failure of the reciprocity law, are smoothed. It is obvious that the sensitizing effect has passed a maximum. The existence of this maximum is shown in the column of values for the 3-minute development in Table VII. We see an increas-

TABLE VII.

$$\frac{Ag_A - Ag_B}{Ag_A} \cdot 100.$$

Step.	Log E.	Time of Dev.			Step.	Log E.	Time of Dev.		
		With 3′.	With 8′.	With 16′.			With 3′.	With 8′.	With 16′.
26	3.60	+24.27	+34.51	+10.59	13	1.65	− 64.50	−27.18	−29.45
25	3.45	+14.42	+33.94	+21.73	12	1.50	− 61.50	−22.43	−29.05
24	3.30	+19.26	+31.34	+21.48	11	1.35	− 92.40	−22.81	−35.42
23	3.15	− 5.26	+33.06	+20.84	10	1.20	−111.11	−34.48	−23.65
22	3.00	− 8.73	+31.99	+11.56	9	1.05	—	−42.92	−25.82
21	2.85	−38.26	+29.44	− 2.76	8	0.90	−138.57	−16.67	−26.71
20	2.70	−90.00	+12.17	− 2.19	7	0.75	−149.24	−42.89	−17.00
19	2.55	−53.15	+ 6.51	− 2.48	6	0.60	−176.47	−49.32	−60.81
18	2.40	−74.27	− 4.30	−23.30	5	0.45	—	−59.71	−45.32
17	2.25	−75.73	+ 0.85	−21.50	4	0.30	−119.87	−56.02	−43.35
16	2.10	−80.19	− 1.65	−29.56	3	0.15	− 72.19	−58.90	−54.03
15	1.95	−	−12.55	−16.13	2	0.00	− 15.61	−94.74	−64.17
14	1.80	−	−17.42	−19.35	−	−	−	−	−

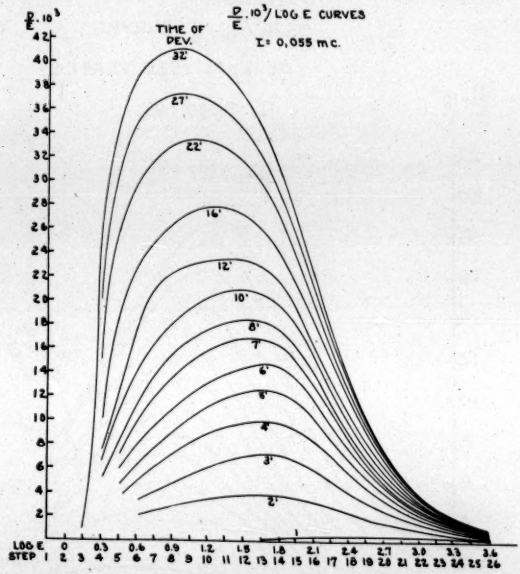
ing sensitizing from step 2 to step 5, after which the sensitizing shows a continuous decrease with increasing exposure until it passes again a zero point without any effect, after which the desensitizing effect starts to dominate for a second time. It seems that the maximum sensitizing effect shifts towards shorter exposures with increased time of development, because of differences in the various layers of grains in the coated emulsion.

The sensitizing effect of the chromic acid treatment is, in this case only, limited to a certain region of exposures. With shorter exposures before this region and with longer exposures beyond this region there is a desensitizing effect. The light intensity of the exposure has an effect on the sensitizing or on the desensitizing action of the chromic acid.

Mr. L. A. Jones of these Laboratories suggested that we express the sensitivity of our photographic material by the

rate of increase of the density per unit exposure D/E plotted against log E. The curves for the low-intensity exposure are given in Fig. 11 for the normal emulsion A, and in Fig. 12 for

FIG. 11.



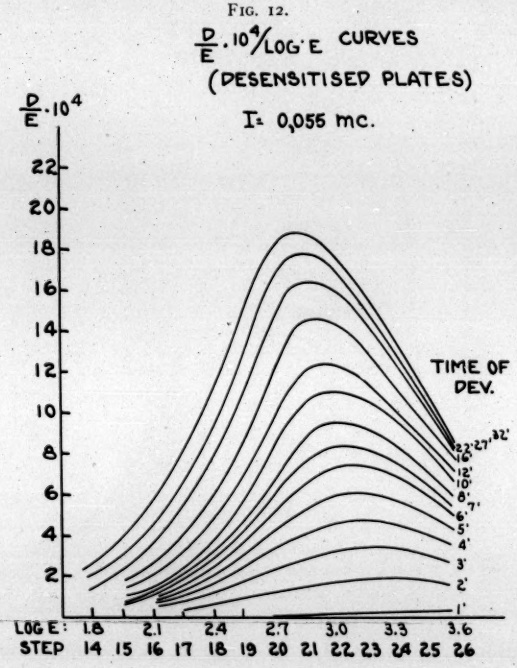
Jones' sensitivity curves for the normal emulsion for low-light intensity exposures.

the treated emulsion B. The data for this emulsion are so small that the abscissa values had to be made 10 times larger than those for the normal emulsion. If on the basis of the silver sulfide-silver speck hypothesis the chromic acid treatment has removed the silver only, without reacting with the silver sulfide speck, we may expect to get only a shift of the curves of Fig. 11 toward higher log E values. In addition to this shift, there is a great diminution of the maximum values of D/E, which seems to indicate that a reaction between the

silver sulfide of the speck and the chromic acid has taken place, and reduced the size of these specks.

This investigation can be extended to the overexposure region with high light intensity. A series of curves for the

FIG. 12.

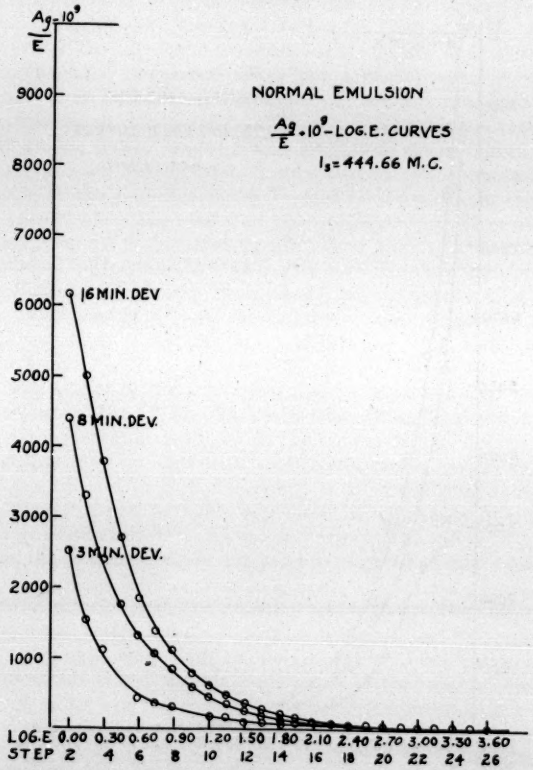


Jones' sensitivity curves for the treated emulsion for low-light intensity exposures.

normal and for the treated emulsion are obtained, which, however, are not comparable because the covering power of the grain of the two emulsions shows differences too great to allow a direct comparison. Instead of the rate of increase of the density per unit exposure we have to use the rate of increase of the silver weights of the developed silver grains per

unit exposure plotted against log E. In the last two columns of Tables I–VI are given the weights of silver divided by the total m.c.s. exposures; in Tables I, II, and III these weights are multiplied by 10^7; in Tables IV, V, and VI, they are multiplied by 10^9. These data represent the rate of increase of

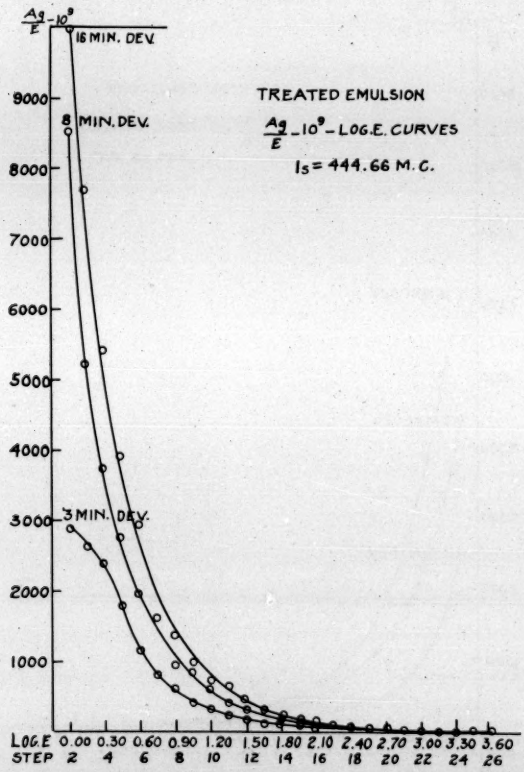
FIG. 13.



The rate of increase of developed silver per unit exposure of the normal emulsion A plotted against log E in the overexposure region.

silver per m.c.s. for the different exposures. The proportionality between the photometric equivalents, between the densities, and between the close values of the covering powers of the normal emulsion *A* and the treated emulsion *B* at low-light intensity exposures allows for direct conclusions from the

FIG. 14.



The rate of increase of developed silver per unit exposure of the treated emulsion *B*, plotted against log *E* in the overexposure region.

$D/E - \log E$ curves. We notice that the curves of Figs. 11 and 12 show a much smaller rate of increase of density or weight of silver of the developed grains per unit exposure after the treatment.

For the high light intensity exposures the $Ag/E - \log E$ curves are plotted in Fig. 13 and in Fig. 14. These show quite different results. Fig. 13 gives the data for the normal emulsion *A* and Fig. 14 gives the data for the treated emulsion *B*. We notice that after the treatment with chromic acid the rate of increase of developed silver per unit exposure is much greater than before the treatment. This is the case with the shortest given exposures in this region. In Fig. 11 and in Fig. 12 we notice that for the longest exposure times the differences are decreasing. Somewhere in the overexposure region, in the shoulder of the H. and D. curve, there should be a point where the rate of increase of developed silver of the treated emulsion becomes greater than that of the normal emulsion. That means that somewhere there is a zero point. In all these comparisons between the low exposure region and the overexposure region, the failure of the reciprocity law requires more investigation to determine this zero point accurately.

The action of the sensitivity specks is pronounced in the first part of the H. and D. curve and diminishes with prolonged exposure as is shown in the curves of Fig. 6 with low exposures and in desensitizing curves previously published (by one of us with S. E. Sheppard in an investigation on the sensitivity of photographic emulsions in relation to quantum energy in exposure).[25] At the shoulder of the curve in most cases the desensitizing action of chromic acid on silver halide grains becomes less, approaching zero, which means from the point of view of the concentration speck theory that the concentrating action of the speck is approaching low values. This is in agreement with Lüppo-Cramer's[26] observation that there is no direct visible difference in the photochemical decomposition of the same photographic emulsion before and after the chromic acid treatment. K. C. D. Hickman[27] was able to show a direct visible action of the silver sulfide

[25] *Phot. J.*, 66: 505 (1926).
[26] Kinotechnik, 11: 285 (1929).
[27] *Phot. J.*, 67: 34 (1927).

specks on the photochemical decomposition of silver halide, but he used in his experiments quantities of silver sulfide which were thousands of times greater than is necessary to show its maximum activity on photographic emulsions of the highest sensitivity.

If, as suggested by one of us, [28] we regard the action of the sensitivity speck as a collecting of silver on an electrode through electrolysis by a Becquerel photo-cell, then it is clear that after exposure this action should diminish, approaching a minimum value near zero, since one of the electrodes is isolated from the surrounding silver halide by the enveloping silver deposits. The silver sulfide-silver speck becomes equal to a silver speck, which causes only a strain in the surrounding silver bromide. Such places will always remain weak spots in the crystal lattice, giving more chance for photochemical decomposition than other places of the crystal lattice. In the microscope we see a continuous enlarging of the silver spots on a silver bromide crystal tablet during exposure. The rapid growth of the silver nucleus of the sensitivity speck is restricted only to shorter exposures.

This investigation has shown that the complexity of the desensitizing curves for high exposures as shown in Fig. 6 is caused by an abnormal silver distribution of the developed grains in the normal emulsion. By using silver weights instead of densities, the curves are simplified. They show in the overexposure region an increase and a second decrease of sensitivity after the treatment with chromic acid. Although more explanations are possible, we offer the following two:

1. It may be due to the formation of a small amount of a decomposition product of the gelatin acting as a halogen absorber. Under the conditions of the chromic acid treatment it can never be formed in large amounts. To show such an increase in density in the first reversal of the solarization after the chromic acid treatment, it must be a very strong halogen absorber. The more active the halogen absorber the greater is the oxidation produced by the chromic acid during the treatment. This explanation we therefore regard as not impossible but very improbable.

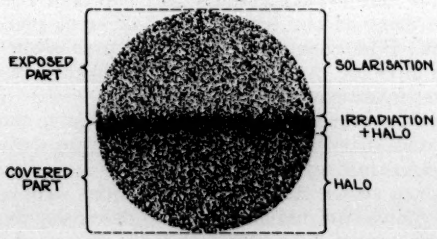
2. We regard the sensitizing action in the overexposure

[28] J. FRANK. INST., 204: 649 (1927).

region as much more probable because of the formation of protein sensitizer by the chromic acid treatment. This indicates that its activity was exhausted after the action of the silver sulfide-silver speck. With extreme exposures this action again diminishes, which would indicate a similarity in the action of the protein sensitizer and the carbamide sensitizer, and would suggest that this action is the same as that explained in the concentration speck theory. In this case there is only this difference, that the protein sensitizer is formed without silver in contact with the speck. Originally there is no photo-electric cell formed; this is made during the exposure, when the first silver forms photochemically at the boundary of the speck and the silver halide. The activity of this protein sensitizer in the overexposure region counteracts the first reversal of the solarization. After its exhaustion by extreme overexposure, the desensitizing action of the chromic acid becomes normal.

During this investigation we observed in the solarized part of the developed strips the appearance of a halo around

FIG. 15.



the exposed steps. The plates were backed before exposure to eliminate, as much as possible, differences in the action of reflected light from the back of the plate, which has been transmitted through different thicknesses of coated emulsion. This prevents the appearance of halo for a considerable region but not entirely. At the maximum density and in the

solarized part the halo appears with increasing density for increasing exposure and increasing time of development. At the boundary of the exposed steps and stretching out in the field of the halo there is a dark line which we explain by the action of scattered light within the emulsion in addition to the halo producing an additional density. In Fig. 15 is given a picture of the edge between a solarized step with 113,833 m.c.s. exposure and the halo in the now exposed part, showing that at 200 × enlargement the effect of irradiation is very pronounced. The development time was 2 minutes.

SUMMARY.

1. The reaction of chromic acid on the sensitivity of photographic emulsions is discussed and it was found to be of a complex nature. This can be analyzed into:

(*a*) A very slow action on the silver halide itself.

(*b*) An action on the silver and on the silver sulfide of the sensitivity speck, with different reaction velocities.

(*c*) An action on the gelatin of partial hydrolysis and oxidation, forming and destroying at the same time a new sensitizer.

2. This may explain the different effects of the chromic acid treatment on the sensitivity of different photographic emulsions. The abnormal action of a pure silver bromide emulsion after the chromic acid reaction in the overexposure region was investigated on this basis.

3. In the overexposure region the desensitizing curves show irregularities that disappear if the curves are derived from silver weights instead of densities.

4. It was shown that these irregularities were caused by increasing silver weights in relation to decreasing densities in the first reversal of the solarization of the untreated emulsion.

5. After the chromic acid treatment the grains of the emulsion develop in the usual way: with silver weights approximately proportional to the densities.

6. An explanation of the sensitizing action of the chromic acid in the overexposure region was suggested on the basis of the concentration speck theory.

THE NATURE AND SOURCE OF PLANT NITROGEN.

BY

S. L. JODIDI, Ph.D.

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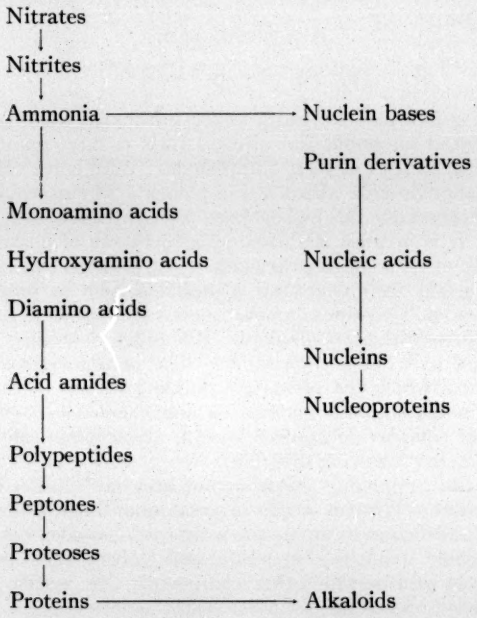
ALTHOUGH plants take up nitrogen from the soil chiefly in the form of ammonia and nitrates their tissues contain but minute quantities of these compounds. Why is it? How is this change brought about in the plants? The reason is that plants, especially the higher ones, are synthesists par excellence. It is because of this singular property of plants that the bulk of their nitrogen is made up of proteins and nucleoproteins and their degradation products such as proteoses, peptones, polypeptides, amino acids, acid amides, nuclein bases, in addition to alkaloids, glucosides, lecithins, phosphatides, and other compounds. The organic nitrogenous substances which the plants are building up out of the two simple inorganic compounds and which, chemically, represent the most complex substances known, are schematically presented in the following diagram.

All the compounds given do not necessarily occur in the same plant. Proteins occur in great quantities in seeds of cereals and legumes; amino acids and acid amides occur in considerable quantities in roots and tubers such as the sugar beet and potato; other compounds like nucleic acids and nuclein bases are found in plant tissues only in insignificant proportions. The true alkaloids on the other hand are found solely in certain families of plants. It is true that we owe to the ingenuity of the chemist the synthesis of many substances such as amino acids, polypeptides, purin bases, sugars, glucosides, dyes (insecticides) and resins, to mention but a few. It is equally true that we may with confidence expect the organic chemist to prepare in the laboratory many more synthetic products. On the other hand it must be admitted that the plant has as yet outdone the chemist in the way of synthesis. Even to the present

time the chemist has been unable to synthesize proteins, nucleoproteins and similar compounds, a process which is accomplished in the plant cell by means of enzymes apparently with the greatest ease.



NITROGEN AN INTEGRAL CONSTITUENT OF LIVING PLANT TISSUES.

No matter whether it concerns sugar producing plants such as the sugar beet, sugar cane, and sweet sorghum; starch producing plants such as the Irish potato; oil producing plants such as the soy bean; or plants producing both protein and starch like the cereals; or cellulose producing plants like the woody plants, in each and every case the plants in question have always some nitrogen in the form of proteins, nucleoproteins and their cleavage products. This is evident when

we realize that proteins are associated with life functions in the plant organism and that they are the most important integral constituent of the protoplast.

SOURCES OF PLANT NITROGEN.

Although the atmospheric ocean surrounding the earth contains countless millions of tons of nitrogen it is as such of little avail since, with the exception of the legumes, plants are unable to utilize the free nitrogen of the air. It is the combined nitrogen that represents the useful, immediately available plant food. Fortunately some of it is present in the air in the form of ammonia and nitric acid. The question naturally arises, how do these compounds happen to be in the air? There is a simple explanation. The ammonia is the result of the decay of organic matter. Generations of plants, of animals, including also humans, after death undergo putrefaction and decomposition whereby the nitrogen is finally liberated as ammonia to escape into the atmosphere, at least in part. So far as nitric acid is concerned it is known that it can be produced by discharges of the electric spark in moist air. Cavendish, the great English investigator, was the first to make the important observation that through frequent discharges of the electric spark the two main constituents of the air, nitrogen and oxygen, are gradually converted into an acid which he was able to identify as nitric. In this connection it is but natural to think of lightning, perhaps the most powerful electric spark known, as an agent that unquestionably causes the nitrogen and oxygen of the air to combine.

CERTAIN PROCESSES OF COMBUSTION LEAD ALSO TO COMBINED NITROGEN.

As early as 1845 the German chemist Schönbein found that the combustion of hydrocarbons, fats, and other materials in the air resulted in the appearance of an oxidizing substance which was able to decompose an indigo solution, to turn iodine-starch blue, and to bring about other oxidations. At that time he was unable to ascertain the exact nature of the oxidizing substance. Later, in 1861, he made the observation that when phosphorus was allowed slowly to burn in moist air white fumes formed which he identified as ammonium

nitrite. The German chemist, Kolbe, demonstrated experimentally that when hydrogen was allowed to burn in the open neck of a flask containing oxygen it soon became filled with the red fumes of nitrous acid. The French chemist Saussure found that the water produced by the combustion of hydrogen in the air contained nitric acid and ammonia. Needless to say that the ammonia, nitrous, and nitric acid produced in the air by the various processes are brought into the soil with each rain, snow, and hail. The quantity of this combined nitrogen varies with the locality, the season, and the year, depending generally on the amount of precipitation. It was found by careful observations that the combined nitrogen annually ranges from 10 to 35 lbs. per acre. In addition to this the free nitrogen of the air is also fixed by microorganisms of which there are two groups, namely bacteria that live free in the soil and symbiotic bacteria that live on the roots of leguminous plants. However, the quantity of nitrogen fixed by all the processes enumerated is usually smaller than the nitrogen removed from the soil by various crops. For this reason nitrogenous fertilizers have to be resorted to in order to maintain the fertility of the soil. Of the fertilizers, those obtained from the nitrate deposits of Chile and those coming as a by-product of coke ovens are of considerable importance, calcium cyanamide playing also a conspicuous rôle as a fertilizer. Within the last fifteen years the so-called Haber process, by which the free nitrogen of the air is made directly to unite with hydrogen gas at high temperatures and pressures, is coming into increasing prominence. Not only is the nitrogen fixed by this method already a powerful competitor with the afore-mentioned sources of combined nitrogen, but it even bids fair to supplant all of them since the chemical nitrogen fixation process can be expanded at will. Actually the process is being improved and expanded continually both here and abroad. The important work of the Fixed Nitrogen Research Laboratory, United States Department of Agriculture, needs no emphasis in this connection. At present more than half the combined nitrogen consumed in the world is supplied by the fixed nitrogen factories.

SIGNIFICANCE OF THE COMPLEX NITROGENOUS COMPOUNDS.

It seems safe to state that among the complex nitrogenous compounds the proteins and nucleoproteins have by far the greatest significance. This follows not only from the circumstance that they have high nutritive value, but a fact still of greater moment is that they must justly be considered as carriers of the most important life functions in plant, animal, and man. This is readily understood when we bear in mind that proteins and nucleoproteins constitute the most significant part of the protoplasm. The amino-acids, too, play an important rôle physiologically and from the standpoint of nutrition. It has been shown conclusively that the cells of the animal organism can with amino acids perform all functions which are known to be associated with proteins. It is further known that nutritive equilibrium may be maintained, at least for short periods, by substituting mixtures of amino acids instead of the dietary proteins. The polypeptides, peptones, and proteoses standing as they do between the proteins on the one hand and the amino acids on the other must necessarily play a rôle similar to those compounds both physiologically and nutritionally. With regard to lecithins and phosphatides it is known that they have a nutritive value about equivalent to that of fats whose chemical structure they resemble. Of overwhelming interest, however, is the conclusion of Professor V. Grafe of Vienna, Austria, based on his researches, that the phosphatides must be considered as the mother substances of the vitamins, the dietary essentials which have been found to be absolutely necessary for maintenance, growth, and reproduction.

Trussless Wood Airplane Hangar Tested for Resistance to Snow Loads and Wind Pressure Shows Slight Deflection. (National Lumber Manufacturers Association Information Service.) The ability of the trussless type all-wood airplane hangar to withstand high wind pressures and heavy snow loads has been conclusively demonstrated by tests recently conducted on a Notrus Hangar belonging to the Great Lakes Aircraft Corporation, Cleveland, Ohio.

The engineers report that a cable pressure of 10,500 pounds applied at three points, ranging from near ground level to near the apex of the structure, and equivalent to a 90-mile wind, produced a maximum deflection of only ¾ inch and an average deflection of only ¼ inch in the arch of the hangar after removal of pressure.

Bags of sand weighing 19,500 pounds, piled for a distance of 25 feet on each side of the hangar's crown, equivalent to a snow load of 30 pounds per square foot, caused a maximum deflection of only ⅝ inch from original positions after removal of the weights.

No evidence of crushing of material at joists, movement of bolts, or splitting of members was found.

The conclusion of the engineers' test report says: "No defects developed . . . the structure meets the Cleveland Building Code."

Estimate of Ruhr Coal Reserves. (*Commerce Reports*, Nov. 11, 1929.) Reliable estimates place coal reserves in the Ruhr district of Germany within a depth of 1,000 meters at 28,500,000,000 tons, within a 1,500-meter depth at 75,000,000,000, and within the limit of coal occurrence at around 250,000,000,000 tons. With an annual output of 100,000,000 tons the 1,000-meter reserves would last about 280 years, the 1,500-meter block about 750, and the limit reserves about 2,500 years.

THE DISTRIBUTION OF LIGHT IN OPTICAL SYSTEMS.

BY

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INTRODUCTION.

EVERY elementary textbook of physics outlines the method of computing the current in an electrical circuit when the electromotive forces and impedances are given. Curiously enough, the analogous problem of computing the distribution of light flux within an optical system [1] from the brightness of the source and the constants of the lenses receives almost no consideration, even in advanced treatises on optics.[2] This situation results from the fact that the photometry of optical systems falls between the field of interest of the lens designer and that of the illuminating engineer. The former is primarily interested in the quality of the image formed by the optical system, which, of course, is independent of the amount of light that it transmits. The latter, on the other hand, is accustomed to distributing light in bulk and uses simple image-forming systems rather infrequently. The purpose of the present paper is to derive certain expressions for the distribution of light within an optical system, based on the conservation of energy principle, and to illustrate the method of applying the results to any optical system whatever by a quantitative study of a few special cases. We will begin by defining the necessary photometric quantities.

PHOTOMETRIC NOMENCLATURE.

There are four important photometric quantities which are commonly accepted as fundamental, although these are

[1] It will be apparent to students of electricity that an optical system behaves in many respects like an electrical circuit consisting of a battery and a number of photoelectric cells of the vacuum type connected in series.

[2] The most notable exception is "Grundzüge Der Theorie der Optischen Instrumente" by Czapski and Eppenstein.

so related geometrically that only one of them is strictly a basic quantity. It is sometimes customary to select the *candle* as the starting point, but it is more rational and certainly more useful for the present purpose to begin with a definition of the unit of *light flux*. This quantity is dimensionally equivalent to power and evaluates the rate of flow of visible energy in the radiation. For monochromatic green light with a wave-length of 546.1 millimicrons, one *lumen*, the conventional unit of light flux, is equal to 0.00163 watt.[3] This ratio of the luminous flux in lumens to the radiant flux in watts is known as the luminous efficiency of the source and depends, in general, upon the distribution of energy in the spectrum of the source and the visibility curve of the human observer. It is sufficient for the present purpose to note the dimensional equivalence of the lumen and the watt in order that the conservation of energy principle may be applied later to the distribution of flux in optical systems.

We define the *intensity* of a point source of light in any particular direction by equation 1,

$$I = \frac{dF}{d\omega}, \tag{1}$$

where dF represents the element of flux in the small solid angle $d\omega$ in the direction considered. The intensity concept may be applied in practice to any source whose dimensions are so small by comparison with the distance at which it is observed that the effect is substantially the same as though it were a mathematical point.[4] The unit of luminous intensity is the *candle*. Thus, a point source radiating uniformly in all directions radiates 4π lumens per candle.

When the light from a point source of intensity I is allowed to impinge normally on a surface at a distance d, the *illumination* of the surface is obtained by dividing the intensity of the source by the square of the distance in accord-

[3] H. E. Ives, *J. O. S. A.* and *R. S. I.*, IX, Dec. 1924, page 635.

[4] Due to the limit of precision in photometric measurements, the light source can usually be treated as a point when its greatest dimension is less than 1/20 of the distance at which its effect is considered. This assumption is almost never possible when computing the distribution of flux in an optical system and much confusion has arisen as a result of attempts to treat extended sources as points.

ance with the well-known inverse square law. If the radiation strikes the surface at an angle θ with the normal, the illumination is reduced in proportion to cos θ in accordance with equation 2.

$$E = \frac{I}{d^2} \cos \theta. \qquad (2)$$

Illuminating engineers in this country are in the habit of expressing I in candles and d in feet, the illumination produced on a normal surface by one candle at a distance of one foot being known as one *foot-candle*. For the present purpose, it is preferable to measure illumination in *lumens per unit of area*, since this definition requires no correction when the radiation falls obliquely on the surface. It will be obvious that the foot-candle is the numerical equivalent of a *lumen per square foot*.

The intensity concept must be modified when the radiating surface is too large to be treated as a point. In this case, the *brightness* of the extended surface from any direction of observation can be expressed in *candles per unit of area*. Of course, the determination of the intensity of this area must be made by observing it from such a distance that it can be treated as a point in the calculations. Incidentally, this brightness concept may be extended to the measurement of the brightness of the sky or any other diffusing medium which could hardly be subdivided into area units.

For a more concise definition of the above quantities, the reader is referred to reports of the Committee on Nomenclature and Standards which are published frequently in the Transactions of the Illuminating Engineering Society. As it is proposed in the present paper to make a quantitative use of these definitions, the units and symbols for the four fundamental quantities—flux, intensity, illumination, and brightness—are listed for convenience in the table below and will be used consistently hereafter.

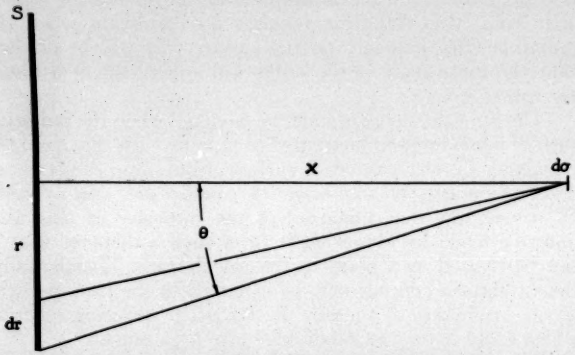
TABLE OF PHOTOMETRIC UNITS AND SYMBOLS.

Quantity.	Unit.	Symbol.
Flux	Lumen	F
Intensity	Candle	I
Illumination	Lumen per square centimeter	E
Brightness	Candle per square centimeter	B

THE ILLUMINATION PRODUCED AT A DISTANT POINT BY AN EXTENDED SURFACE OBEYING LAMBERT'S LAW.

We have already seen that the illumination at any distance from a point source of known intensity can be computed from the inverse square law. When the dimensions of the source are such that they cannot be neglected, the illumination is determined by dividing the source into small areas after the manner of the integral calculus. One special case, which will be of interest later, will serve as an illustration. Suppose that S in Fig. 1 represents a circular source and

FIG. 1.



that it is desired to calculate the illumination on a small area $d\sigma$ situated at a distance x along the normal from the center of the circle. If the source is divided into circular zones of radius r and width dr, the illumination dE produced at $d\sigma$ can be computed from the inverse square law. Thus

$$dE = \frac{dI}{x^2 \sec^2 \theta} \cos \theta, \qquad (3)$$

where dI is the intensity of the elementary zone in the direction of $d\sigma$.

If we assume the radiating surface obeys Lambert's law of emission or reflection, the intensity of this elementary zone in the direction of $d\sigma$ varies directly as $\cos \theta$. However, the

effective area of the zone varies inversely as cos θ so that the surface appears equally bright from any angle of observation. Such a surface is said to be perfectly diffusing and a rather large class of materials obey this law approximately. If we designate the uniform brightness of this surface by B, the intensity of the elementary circular zone in the direction of $d\sigma$ is the product of B and its effective area. The area dS of this elementary zone is $2\pi r dr$ and the effective area is $dS \cos \theta$. The illumination produced at $d\sigma$ by the elementary zone of the source is then given by equation 4.

$$dE = \frac{2\pi r dr \cos \theta B}{x^2 \sec^2 \theta} \cos \theta. \tag{4}$$

The total illumination due to the entire area of the source is obtained by integrating this expression. This can be done most easily by eliminating x and r in favor of θ and integrating between the limits zero and θ, making use of the fact that

$$r = x \tan \theta$$

and

$$dr = x \sec^2 \theta d\theta.$$

The value of E is then given by equation 5 below.

$$E = \int_0^\theta 2\pi B \sin \theta \cos \theta d\theta. \tag{5}$$

The well-known result of this integration is given in equation 6.

$$E = \pi B \sin^2 \theta. \tag{6}$$

It is interesting to note that the illumination at $d\sigma$ is given approximately by the product of B and the solid angle which the source subtends from $d\sigma$. The solid angle ω within the cone whose half plane angle is θ is given in equation 7.

$$\omega = 2\pi(1 - \cos \theta). \tag{7}$$

For small values of θ, $2(1 - \cos \theta)$ is equal to $\sin^2 \theta$ so that equation 8 applies rigorously when the source subtends a small solid angle at the point where the illumination is to be calculated.

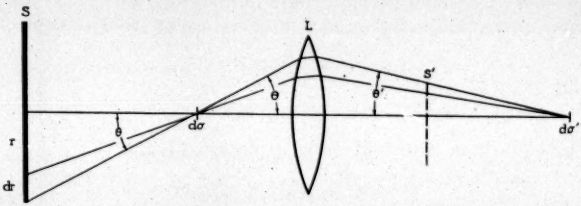
$$E = B\omega. \tag{8}$$

When the source is of considerable size, equation 8 leads to values which are somewhat too large, the maximum error occurring when the source is an infinite plane. In this case, the illumination indicated by equation 8 is twice as great as is indicated by the rigorous formula given by equation 6. However, for most optical systems, ω is small enough so that the approximation is justified, and when the source is not circular it is exceedingly useful because the rigorous formula is inapplicable.

THE ILLUMINATION AT A POINT ON THE AXIS OF AN OPTICAL SYSTEM.

We are now in a position to consider the illumination produced at any point along the axis of an optical system. In Fig. 2, the circular source S is imaged by means of the

FIG. 2.



lens L at S'. We have already seen that the illumination at any point on the axis at the left of L can be computed by equation 6. To compute the illumination for points on the axis at the right of L, let us consider the flux incident on some small area such as $d\sigma'$. Let us suppose that the small area $d\sigma'$ is the image by L of a small area $d\sigma$ at the left of L. The total flux through the area $d\sigma$ is obtained by multiplying its illumination by its area. As all this flux falls on the area $d\sigma'$, the illumination (E') of $d\sigma'$ is obtained by dividing this flux by $d\sigma'$, as indicated in equation 9.

$$E' = \pi B \sin^2 \theta \frac{d\sigma}{d\sigma'}. \qquad (9)$$

The relation between $d\sigma$ and $d\sigma'$ depends to some extent on the degree of perfection of the lens. If the lens is in air

and obeys the well-known sine condition,[5] the ratio of $d\sigma$ to $d\sigma'$ is given by equation 10.

$$\frac{d\sigma}{d\sigma'} = \frac{\sin^2 \theta'}{\sin^2 \theta}. \tag{10}$$

When this ratio is substituted in equation 9, we obtain equation 11,

$$E' = \pi B \sin^2 \theta', \tag{11}$$

which gives the illumination of $d\sigma'$ in terms of the brightness of the source and the value of the half angle of the cone of light incident on $d\sigma'$. For small values of θ', we may make an approximation similar to that of equation 8 and state that the illumination at any point on the axis of an optical system is the product of the brightness of the source and the solid angle of the cone of light incident at the point in question. It appears that, as far as the effect at $d\sigma'$ is concerned, the brightness of the image S' is the same as that of the source S.

Equation 11 is so fundamental in the photometry of optical systems that it may be well to pause at this point to consider the two explicit assumptions made in its derivation, namely, that the source obeys Lambert's law of emission or reflection and that the lens fulfills the sine condition. It has already been stated that a surface obeying Lambert's law appears equally bright from every direction of observation. This is equivalent to a distribution of intensity about the axis of symmetry proportional to the cosine of the angle from the axis. Although no surface ever obeys this law exactly, it is remarkable that even such light sources as carbon arcs or tungsten filament projection lamps obey it approximately within the angle ordinarily utilized, except for shadows cast by the supporting mechanism. Whenever the distribution of intensity from the source is such that Lambert's law cannot be assumed, the problem becomes so complicated that graphical methods of treatment are necessary.

The sine condition can be shown to be a consequence of

[5] The full expression for the sine condition is as follows:

$$nh \sin \theta = n'h' \sin \theta',$$

where n and n' are the refractive indices of the initial and final media and h and h' represent respectively the size of object and image. The quantities $d\sigma$ and $d\sigma'$ represent areas which are proportional to the squares of h and h'.

the conservation of energy principle by assuming the object and image planes to contain black bodies or complete radiators. As the details of the proof are readily available,[6] they will be omitted from the present discussion. It is important to note, however, that equation 11 assumes a perfect optical system in this sense and that, as a corollary, no system can be devised to provide more illumination than equation 11 indicates. We have tacitly assumed no loss of light in the media or in the material of the lens. Although in actual practice the media are usually transparent enough, there is a loss by reflection at each air-glass surface amounting to approximately 5 per cent. of the light incident at that surface. The absorption of light in optical glass depends upon the kind of glass and the quality, and varies from 0.5 per cent. to 1.5 per cent. for a thickness of one centimeter. We shall consistently ignore these losses in the following discussion and the results will be strictly applicable only to optical systems which are perfectly transparent and which are free from aberrations, as indicated by the fulfillment of the sine condition. The illumination in any actual case will be less than that indicated for the ideal case by an amount which is a measure of the efficiency of the system.

THE EFFECT OF APERTURES.

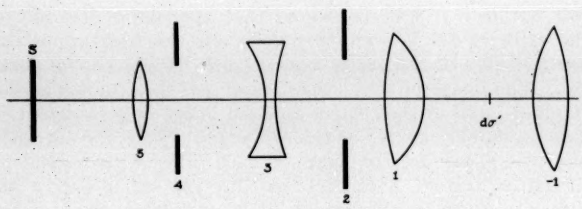
Figure 2 has been drawn to represent the case where θ is limited by the diameter of the source. Since S' is the image of S, a ray from any point of S will pass through the conjugate point of S'. In other words, as far as the illumination of $d\sigma'$ is concerned, S' is as effective in limiting θ' as though a real aperture were located there. In fact, an observer looking to the left from $d\sigma'$ would be unaware of the presence of both the source S and the lens L and would see only S'. Of course, the value of θ' could be limited by the size of the lens if it were smaller. Similarly, if any other aperture were introduced between S and L, the effect at $d\sigma'$ would be the same as though an aperture of the proper size were placed at its image formed by L. This statement must be construed liberally since an aperture between $d\sigma$ and L would be imaged on the right of $d\sigma'$, where a real aperture could have no effect

[6] See, for example, "The Theory of Optics," by Drude, 1925 edition, page 505.

on the illumination of $d\sigma'$. In this case, the value of θ' is computed just as before by determining the angle which this image subtends at $d\sigma'$.

Although Fig. 2 shows only a single lens, the assumptions made in the derivation of equation 11 are so general that the method applies to any optical system regardless of its complexity. Assume in Fig. 3 that an extended source of

FIG. 3.



light S illuminates the small area $d\sigma'$ situated on the axis of the optical system and that it is desired to know the value of the illumination at that point. Obviously the value of θ' at $d\sigma'$ will depend either on the size of the source S or on the size of one of the apertures from 1 to 5. Since it is not known which one of these is effective in limiting the angle of the cone incident on $d\sigma'$, we begin by suspecting aperture 1 which happens, in this case, to be a lens. The half angle of the cone, whose base is the lens 1 and whose apex is $d\sigma'$ is computed and tabulated for future reference. We then pass on and suspect aperture 2. Since lens 1 lies between 2 and $d\sigma'$, we must first determine the size and position of the image of 2 formed by 1. The angle which the edge of this image subtends from $d\sigma'$ is likewise computed and tabulated. In similar fashion, the image of the rim of lens 3 formed by lens 1 is determined in size and position, and the angle which it subtends from $d\sigma'$ is also tabulated. Aperture 4 is imaged by lens 3 and this image is the object for lens 1. The image formed by lens 1 of this virtual object is computed in size and position, and the angle which it subtends from $d\sigma'$ tabulated as before. This process is continued until the angle subtended by the image of S formed by lenses 5, 3, and

1 has been tabulated. We then examine the table and take the smallest value of θ' for substitution in equation 11. The lens -1 shown in Fig. 3 can have no effect on the illumination at $d\sigma'$ but is included in the drawing to indicate that the method can be applied to any point on the axis of an optical system.

The above treatment of a complex optical system may be greatly simplified by introducing a nomenclature due to Abbe. Suppose for example that, as a result of the process just outlined, it was discovered that aperture 2 determined the value of θ'. We will then designate this aperture as the *aperture stop* of the entire system with respect to the point $d\sigma'$. The image of 2 by lenses 3 and 5 is then known as the *entrance pupil* of the system and the image of 2 by lens 1 is correspondingly known as the *exit pupil*. Since the entrance and exit pupils are conjugate to each other with respect to the entire system, it follows that any ray which enters the entrance pupil in the object space will leave the system from a corresponding point of the exit pupil in the image space. In other words, as far as the limitation of rays is concerned, any optical system regardless of its complexity may be replaced by an entrance and an exit pupil. Since S' in Fig. 2 is the exit pupil of that system, we may generalize the proposition following equation 11 and state that the illumination at any point on the axis of an optical system is the product of the brightness of the source and the solid angle subtended by the exit pupil at that point.

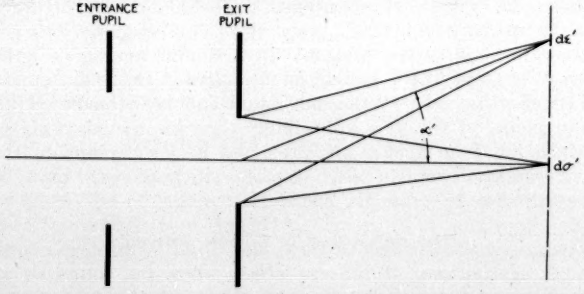
It should be noted that, in the most general sense, the aperture stop and the pupils depend upon the point of reference. This is illustrated in Fig. 2 which shows S as the aperture stop with respect to $d\sigma'$ and S and S' as the corresponding entrance and exit pupils. For other points of reference, however, L is the aperture stop of the system. This will be obvious if we consider the variation in illumination along the axis of the lens, starting for convenience at a point which is located behind the lens at an infinite distance. For this point, S is the aperture stop and S' is the exit pupil but the illumination is zero. As we move inward along the axis, the illumination increases approximately as the inverse square of the distance from S'. A point is eventually reached

where L and S' subtend the same angle, and beyond this point L is the aperture stop and also the entrance and exit pupil. As we move farther inward, the illumination continues to increase until a point is reached between L and S' where both again subtend the same angle. Between this point and L, S' is again the exit pupil but the illumination decreases. Consequently, the maximum illumination does not occur in the image of the source but rather at a point between the lens and the image where both act momentarily as the exit pupil.

THE ILLUMINATION AT POINTS WHICH ARE NOT ON THE AXIS OF THE OPTICAL SYSTEM.

An exact expression for the illumination at points off the axis, corresponding to equation 11, is impracticable because of difficulties in performing the integration but the following method leads to approximate values for points in the neighborhood of the axis. An optical system is represented in Fig. 4

FIG. 4.



by the entrance and exit pupils determined with respect to the small element of area $d\sigma'$ on the axis. We have already seen that the illumination of $d\sigma'$ is the product of the brightness of the source and the solid angle subtended at this point by the exit pupil. Let us now consider the illumination of $d\Sigma'$ in the plane of $d\sigma'$. Unless $d\Sigma'$ is too far from the axis, the illumination may be computed in the same manner provided we correct for the fact that the radiation now falls

obliquely on $d\Sigma'$. This is expressed by equation 12

$$E' = B\Omega \cos \alpha' \qquad (12)$$

where E' is the illumination at $d\Sigma'$, B is the brightness of the source, and Ω is the solid angle subtended by the exit pupil at $d\Sigma'$.[7]

When $d\Sigma'$ is not in the neighborhood of the axis, the illumination is generally affected by the other stops in the system. For example, if we return to Fig. 2 and consider the illumination in the plane of $d\sigma'$, we know that it will decrease as we recede from the axis approximately as the fourth power of the cosine of the angle which the distance of $d\Sigma'$ from the axis subtends at the center of S'. This proposition ceases to be true when the effective area of the exit pupil S' is further reduced by the presence of L in the system. Since the effective rays at $d\Sigma'$ must pass through both L and S', the useful area of S' is limited to that portion through which rays from L will arrive at $d\Sigma'$. This treatment of the problem may be generalized in terms of the system shown in Fig. 3. If we assume, as before, that aperture 2 is the aperture stop with respect to $d\sigma'$, its image by lens 1 is the exit pupil of the system. In a similar manner, all the lenses or stops in the system have images in the image space. The effective area of the exit pupil can be determined for any point off the axis by making a perspective drawing in which all these images are projected into the plane of the exit pupil. The free area of the exit pupil can then be measured and used in the calculation of Ω.

THE SPECIAL CASE OF A POINT SOURCE.

A special case of interest arises when the source is so small or so distant from the optical system that the size of the image is determined by the laws of diffraction rather

[7] It is interesting to note that the illumination decreases as the fourth power of cos α' as we recede from the axis. One cosine term is accounted for by the obliquity of the radiation incident on $d\Sigma'$. Then there is a reduction of the effective area of the exit pupil, which is likewise proportional to cos α'. Also, the distance from the center of the exit pupil to $d\Sigma'$ is greater than the corresponding distance to $d\sigma'$ by sec α'. Since the solid angle Ω is obtained approximately by dividing the effective area of the exit pupil by the square of the distance to $d\Sigma'$, Ω at $d\Sigma'$ is less than ω at $d\sigma'$ by $\cos^3 \alpha'$. This makes four cosine terms in all.

than the laws of geometrical optics. If the optical system is perfect, as far as the laws of geometrical optics are concerned, the image of a point consists of a bright central diffraction disc surrounded by alternate dark and light circular rings. The diameter of the central disc, which contains about 84 per cent. of the light, is given by equation 13,

$$d = 1.22 \frac{\lambda}{\sin \theta'}, \qquad (13)$$

where λ is the wave-length of the light and θ' has the same significance as before. The illumination in the central diffraction disc is determined with sufficient accuracy for most purposes by multiplying the illumination at the entrance pupil by the ratio of the area of the entrance pupil to the area of the diffraction disc, since approximately the same flux traverses both. The illumination of the entrance pupil, in the case of a point source, is easily determined from the intensity of the source and the inverse square law. Although we have treated the illumination in the image only, the distribution of flux at other points within the system is of no practical value in view of the small amount of radiation received from any source of finite brightness which can be treated as a point.

THE PHOTOMETRY OF VISUAL INSTRUMENTS.

It is interesting, as an application of the foregoing, to compute the illumination on the retina produced by an extended source of a given brightness. The minimum objective brightness that is just perceptible to the dark-adapted eye is about 2×10^{-10} candle per square centimeter. The diameter of the exit pupil of the eye under these conditions is approximately 7 millimeters and it is located 19 millimeters in front of the retina. Before substituting in equation 11, however, we must make allowance for the fact that the retina is situated, not in air, but in a medium having a refractive index of 1.337. For this reason, it is necessary to use the complete form of the sine condition given in footnote 5. This requires the illumination indicated by equation 11 to be increased in the ratio of the square of the relative refractive

indices. By substitution, we find that an objective brightness of 2×10^{-10} candle per square centimeter produces an illumination of 1.2×10^{-10} lumen per square centimeter on the retina under the assumed conditions. With an exit pupil 7 millimeters in diameter, the diameter of the central diffraction disc in the image of a point is roughly 0.004 millimeter [8] by equation 13. Since the entrance and exit pupils of the eye are approximately equal in size, we should expect to be able to distinguish a point source of light one mile away with the unaided eye if its intensity is 0.00001 candle or more.[9]

The performance of visual instruments is best illustrated by considering the eye as part of the optical system. All such systems then have the common property of forming a real image on the retina of a real object in the object space. From this standpoint, it is obvious that the size of the cone of light arriving at a point on the retina can in no case exceed the limiting angle set by the pupil of the eye. Thus, no optical system that can be placed before the eye is capable of making an extended object appear brighter than it does to the unaided eye. The retinal illumination may be reduced, however, if the pupil of the eye is not the aperture stop of the system. The case is very different when the object is so small or so distant that the size of the retinal image indicated by the laws of geometrical optics is less than the diameter of the diffraction disc given by equation 13. As we have seen previously, the illumination in this case depends on the ratio of the area of the entrance pupil to the area of the diffraction disc. Thus, it is said to be possible to see stars in the daytime with a telescope of sufficient size, since the illumination in the retinal image of the star increases with the size of the telescope while the illumination in the image of the sky remains constant.

The magnification in any visual instrument should ordinarily be sufficient to permit the eye to see all the details

[8] The distance between adjacent rods and cones of the retina is just slightly less than this value so the limit of visual acuity is ordinarily determined by the size of the pupil rather than the structure of the retina.

[9] This figure represents the absolute threshold of vision and assumes further that the stimulation of a single rod or cone is sensed as easily as though a considerably larger retinal area had been stimulated.

resolved [10] by the instrument. This condition is fulfilled when the aperture stop of the whole system, including the eye, is located in the instrument. On the other hand, we have seen that the maximum illumination on the retina occurs when the stop is in the eye. The best compromise occurs when the aperture stop is in both places. For example, consider the case of a telescope objective having a diameter 10 times as great as the entrance pupil of the eye. This has an inherent resolving power 10 times as great and collects 100 times as much light. The eye will be able to recognize all the details resolved by this objective when the linear magnification is ten-fold or greater. When the retinal image is 10 times larger in linear dimensions than with the unaided eye, the increased light-gathering power of the objective is just sufficient to produce the same retinal illumination. If the magnification is greater, no more detail can be seen and the retinal illumination decreases. For this telescope, 10 is then said to be normal magnification. It is easily shown that any visual instrument used at normal magnification permits all the detail resolved by the instrument to be seen and leaves the brightness of an extended object unaltered except for losses within the instrument. For practical reasons, it is sometimes desirable to depart from the normal magnification. In the Galilean type of telescope, for example, normal magnification would so restrict the field of view that the instrument would be quite useless for its purpose.

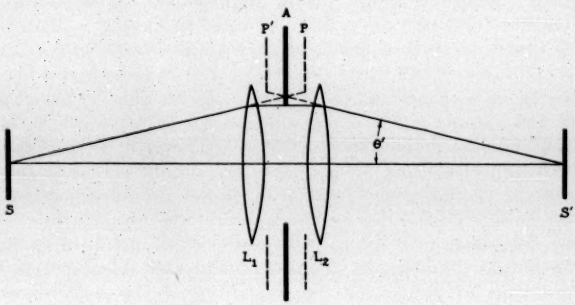
THE PHOTOGRAPHIC OBJECTIVE.

Let us next consider one of the simplest optical systems in which a real image is formed, namely, the photographic objective. For the sake of simplicity, this has been assumed in Fig. 5 to consist of two simple elements with a central diaphragm A. The object plane S is conjugate to the image plane S' by the whole system, while the diaphragm A is imaged by the lens L_2 at P'. Consequently, P' is the exit pupil with respect to S' and determines the value of θ'. The usual method of specifying the speed of a photographic objective is in terms of the so-called f/-number. This is

[10] Two points, such as double stars, are said to be just *resolved* when the center of the diffraction disc of one coincides with the first dark ring of the other. No amount of magnification will separate two overlapping diffraction patterns.

the ratio of the diameter of the entrance pupil to the focal length of the objective. In a symmetrical objective, the entrance and exit pupils are the same size and are located in the principal planes. For this case, the f/-number is 2 tan θ'.

FIG. 5.



As a numerical example of some use to photographers, let us consider a photographic objective having a relative aperture of f/8, which is the stop commonly employed in snapshots of exterior scenes under good lighting conditions. For this stop, we find by substituting in equation 11 that the illumination on the film in lumens per square centimeter is very nearly 1/100th of the objective brightness in candles per square centimeter, after allowance is made for losses in the objective. Photographic materials differ in sensitivity but the ordinary range of exposure of high speed negative materials lies between 0.000002 and 0.0002 lumen-second per square centimeter of area. In other words, an exposure of one second to an illumination of 0.000002 lumen per square centimeter, or the equivalent, will produce a just-perceptible deposit when the film is developed. As a result of our calculations, we see that an objective brightness of 0.0002 candle per square centimeter will produce a just perceptible deposit in one second with the lens in question. This agrees quite well with photographic experience but it should be remembered that the above data were determined for a source having approximately the same spectral distribution

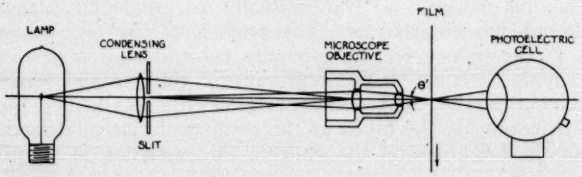
of energy as average noon sunlight and that the result with other sources might be subject to rather large errors.

An interesting case develops when the source S is at the first focal point of the objective. This is the system employed in a searchlight and the following argument applies equally well to either the mirror or lens type. Since the image of S is at infinity, the rim of the lens or mirror is ordinarily the exit pupil of the system for all points at any considerable distance from the searchlight. We have seen that the illumination at any point on the axis is very nearly proportional to the solid angle subtended by the exit pupil at that point. Consequently, the beam of the searchlight produces an illumination which is very nearly inversely proportional to the square of the distance from the searchlight. It may be remarked in this connection that the notion of a parallel beam of light which appears so frequently in the elementary texts is grossly misleading.

THE OPTICAL SYSTEM FOR REPRODUCING SOUND RECORDED ON MOTION PICTURE FILM.

As a further illustration of the application of the foregoing principles, let us consider a typical optical system such as might be used for the reproduction of sound in a modern motion picture theatre. Systems of this sort have been treated by the present author at greater length in a previous paper [11] and we will consider here only the one illustrated in Fig. 6. The source in this case is a lamp containing a

FIG. 6.



ribbon of tungsten for the filament and an image of this is formed by the condensing lens on the microscope objective. The microscope objective, in turn, forms a very much reduced

[11] "The Optics of Sound Recording," *Transactions of the Society of Motion Picture Engineers*, Vol. XII, No. 35, 1928, pp. 760–777.

image of the slit on the film. As the film moves downward, the flux received by the photoelectric cell varies in accordance with the record on the sound track.

It is obvious that the illumination at the film can never exceed the value fixed by the numerical aperture of the microscope objective.[12] Assuming sin $\theta' = 0.25$ and the brightness of the ribbon filament to be 1200 candles per square centimeter, the maximum illumination at the film is 23.6 lumens per square centimeter. This illumination will be obtained only when the magnification of the lamp filament is such that the microscope objective is completely filled with light. In other words, the microscope objective must be the aperture stop of the system. As the area of the slit image on the film used in reproducing is roughly 0.0005 square centimeter, the total flux reaching the photoelectric cell is about 0.1 lumen. Most photoelectric cells have a sensitivity ranging from 10 to 50 microamperes per lumen so that the photoelectric current to be expected with a perfect optical system under the assumed conditions, is of the order of 1 to 5 microamperes. This figure is in good agreement with actual practice.

THE PHOTOMETRY OF OPTICAL SYSTEMS CONTAINING CYLINDRICAL LENSES.

Certain special optical systems require the use of cylindrical lenses for maximum efficiency, and systems of this sort have been treated in two previous papers by the present author.[13] The method consists essentially in applying the preceding notions to two mutually perpendicular planes through the optical axis. The product of the two values of θ', determined for the mutually perpendicular planes of reference, is equal to the solid angle of the pyramid which illuminates the axial point in question. As before, the illumination can be taken as the product of this solid angle and the brightness of the source. The variation in illumi-

[12] The numerical aperture of a microscope objective is numerically equal to sin θ' when used reversed as shown in the figure and at the same magnification for which it was designed.

[13] "The Optical System of the Oscillograph and Similar Recording Instruments," *J. O. S. A.* and *R. S. I.*, Vol. 14, No. 6, June 1927, and "The Optics of Sound Recording," *Transactions of the Society of Motion Picture Engineers*, Vol. XII, No. 35, 1928, pp. 760–777.

nation for points off the axis can be determined in a similar fashion.

CONCLUSION.

In the preceding pages, we have considered a method of determining the illumination at any point within a centered optical system obeying the sine condition. Since the sine condition can be derived from the conservation of energy principle, it follows that no system can produce more illumination than an ideal system of this sort. This provides a basis for rating the performance of any actual system, which must always give less illumination than the ideal system because of lens aberrations and losses by absorption or reflection. The two cases considered, namely, a point source and an extended source obeying Lambert's law are likewise ideal conditions, one or the other of which is approximated by the majority of actual sources.

Melodrama Up to Date. (*Railway Age*, Nov. 9, 1929.) With paint on passenger coaches blistered and charred holes in the roofing, a passenger train on the Hudson Bay extension of the Canadian National limped into The Pas, Man., recently. It had successfully run the gauntlet through three miles of smoke and flames of a forest fire. Before taking the plunge, the train stopped and the crew reconnoitered. The passengers were eager to get through. It was decided to make the dash. Once through the furnace of blazing timber, the train again stopped and the crew cleared the roofs of the cars of flaming sticks and put out several small fires.

Large Earth Dam Planned in Wyoming. (*Engineering News Record*, Nov. 7, 1929.) The largest earth dam in Wyoming except the reclamation service's Gurnsey dam across the North Platte River, is to be completed 35 miles northwest of Cheyenne on North Crow Creek in time to conserve spring floodwaters in 1930. The dam is to be 86 ft. high, 486 ft. thick at the base, and 608 ft. long at the crest. Designed by Reclamation Service engineers to impound waters of North Crow in a 1,300-million-gallon basin, the project is to cost approximately $250,000 and should supply the needs of Cheyenne for at least fifteen years.

A PROPOSED CYCLE OF STELLAR EVOLUTION.

BY

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THE greatest difficulty confronting the assumption of a stationary condition of the universe is the finding of an adequate source of energy for the maintenance of the high temperatures of the stars. The sources suggested by Nernst [1] and others are possibilities rather than probabilities and none of them seems fully to fit the observed facts.

A new and what may prove to be an entirely adequate source is suggested by Brush's [2] researches. He shows with apparent conclusiveness that certain substances are maintained at a measurably higher temperature than their surroundings by the absorption of some exceedingly penetrating form of energy pervading space. It seems reasonable to assume that this property is not exclusive with the substances in which Brush has definitely detected it but to a variable and lesser degree is possessed by all matter. In fact, if the absorbed energy is related to the known forms of radiant energy—by far the most probable conclusion—it would be extraordinary indeed if it were not to some extent absorbable by all matter. The required specific absorption rate is surprisingly small: to account for all the sun's radiation an average absorption of only .006 calorie per cubic meter of the volume occupied by the sun is necessary per minute. A universal absorption of this intensity is outside the range of any existing calorimetric apparatus.

One consequence of such an assumption can be used as a general check: since absorption is proportional to volume and radiation to surface area, the intensity of radiation of a homogeneous sphere in isolated equilibrium must be proportional to its diameter. By further assuming the absorption propor-

[1] JOURNAL OF THE FRANKLIN INSTITUTE, August 1928.

[2] *Ibid.*

tional to density we should expect to find isolated spheres in equilibrium radiating with intensities related to their diameters and densities. Considering the obvious deviations from the ideal conditions of the example, this expectation is in general accord with the observed state of the universe.

This same assumption of a continual absorption of energy is capable of removing two great inconsistencies from Nernst's hypothesis. One of these, which Nernst formulates, is that there have been observed no great numbers of cold stars such as must be in existence as the end product of any process of energy release through disintegration of matter. The second is the extreme improbability of the sudden generation of new-born giant stars through the combination of scattered inert matter. One would expect any such accumulation to be so gradual that the disintegration through radiation would balance the increase in size long before the largest observed stars could be formed.

With the postulation of a general continual absorption of energy both of these difficulties vanish, since disintegration is no longer an essential part of the picture. Eddington and Russell have however developed exceedingly strong evidence of a stellar evolution series with observable examples in every stage. A stationary picture of this kind is practically proof of progressive change but it is unavoidably ambiguous concerning the direction of that change. So long as it was considered necessary to find the source of stellar radiation within the star itself only one direction seemed possible, that of disintegration. Now that a sufficient source of external energy has been postulated the reverse direction, that of integration, may be considered.

The conception of stellar evolution as a building up process is obviously subject to neither of the difficulties which hamper the disintegration evolution theory for neither a cold end product nor a beginning at high energy content is indicated by it. Instead there are required: a source of building material, a limitation in maximum attainable intensity, and a mechanism of return to the starting point. Each of these essentials is ready to hand. Meteorites and the dark matter scattered through interstellar space furnish available material for slow accumulation; growth in intensity—which under the

absorption theory is a necessary consequence of growth in mass—is limited by the internal temperature at which the light pressure will cause an explosion, about 30,000,000 degrees according to Eddington; the starting points are plausibly the nuclei scattered by such explosions which may likewise be assumed as the source of a large part of the scattered matter subsequently used for building.

Only one link in the chain is now missing—the source of the all-pervading energy whose presence Brush has detected. We see energy going out; any theory of a stationary condition presupposes a return of energy; Brush has detected a form of return which has been shown capable of maintaining a balance; what more reasonable than to assume that through some transformation in the remote interstellar spaces the outgoing form, to which matter is impenetrable, has become converted to the returning exceedingly penetrating form? The nature of this transformation is now almost beyond the reach even of speculation, locked up in the mysteries of the nature of radiation, but it may be that the penetrating cosmic radiation investigated by Kolhoerster and more recently by Millikan has something to do with it. In this conception electrons, protons and radiant energy shot out by the stars get together somehow in the interstellar laboratory to produce atoms and molecules of matter plus penetrating radiation, which may include also the form responsible for the Brush effect.

All the essentials have now been presented for the construction of a complete general theory of stellar evolution: The larger bodies among matter scattered by the explosion of a star grow by gravitational agglomeration. Energy is continually absorbed throughout the interior of each body thus raising its entire temperature, which in turn causes it to emit radiant energy and radioactive emissions approximately balancing the absorbed energy. The radiated energy and emitted particles undergo transformations in interstellar space into penetrating absorbable energy and gravitationally accumulatable matter. Thus the reservoir of absorbable energy is maintained at a constant level. As growth continues the temperature and the intensity of radiation increase on account of the decreasing ratio of radiating surface to absorbing

volume. Finally an internal temperature is reached which gives rise to such an enormous light pressure within the star that it explodes, scattering its matter over a wide space.

In conclusion, the contention is made that the apparent violation of the Second Law of Thermodynamics involved in an hypothesis of a stationary condition is of similar nature to that inherent in the kinetic theory of heat which requires great instantaneous variations in energy content among the individual matter particles in a dead level thermal condition. By analogy on a vastly increased scale the stars are the molecules of the galaxies and their evolution periods are individual energy cycles in a statistically dead level thermal condition.

NOTES FROM THE U. S. BUREAU OF STANDARDS.*

U. S. MOTOR GASOLINE.

FOR the past five years the following distillation range has determined the volatility of U. S. Government Motor Gasoline:

Initial point, not more than 55° C. (131° F.).
20 per cent. point, not more than 105° C. (221° F.).
50 per cent. point, not more than 140° C. (284° F.).
90 per cent. point, not more than 200° C. (392° F.).
End point, not more than 225° C. (437° F.).
Recovery, at least 95 per cent.

During this period the semi-annual motor gasoline surveys conducted by the Bureau of Mines have indicated that the average motor fuel sold throughout the country was considerably more volatile even in summer than the gasoline likely to be furnished under the above specification while fuel research at this Bureau has indicated that the 10 per cent. point and 90 per cent. point furnish the most reliable criteria of the relative volatility of fuels for use in automotive engines.

Consequently the Federal Specifications Board has issued recently a revised Federal Specification (USGMS 622a) for motor gasoline which substitutes for the initial point and 20 per cent. point the following requirement:

"When 10 per cent. has been recovered in the receiver, the thermometer shall not read more than 80° C. (176° F.) nor less than 50° C. (122° F.); provided that, for each per cent. distillation loss less than 4 per cent., obtained in the A. S. T. M. distillation, the minimum 10 per cent. temperature requirements shall be lowered 3° C. (5.4° F.)."

Government purchasing officers are authorized to contract for motor gasoline having a maximum 10 per cent. point of 75° C. (167° F.) or 70° C. (158° F.) to meet low temperature conditions. The purpose of the minimum 10 per cent. point at 50° C. (122° F.) is to eliminate gasolines of abnormally

* Communicated by the Director.

high vapor pressure which are subject to excessive losses on storage and may boil in the fuel lines under high temperature conditions. The specification permits raising the minimum 10 per cent. point to 60° C. (140° F.) in the case of gasolines intended for tropical storage.

A separate Federal Specification (U. S. G. M. S. 623) has been written for a special grade of fuel to be used for ambulances, fire engines and other emergency vehicles. This fuel is called motor fuel V and is intermediate between motor gasoline and aviation gasoline.

MORE EFFICIENT USE OF CUTTING FLUIDS IN MACHINE SHOP PRACTICE.

THE Bureau of Standards has been cooperating with the Special Research Committee on Cutting of Metals, American Society of Mechanical Engineers, in coordinating the information available on cutting fluids, and in planning a two-year program of experimental investigation. At the present time the practices in different shops are widely divergent. More efficient selection and use of cutting fluids should result in reduced costs of production of metal parts in every manufacturing industry.

Progress Report No. 1 of the sub-committee on cutting fluids, entitled "Cooling and Lubricating of Cutting Tools," has recently appeared in *Transactions American Society of Mechanical Engineers* (Vol. 51, M. S. P. No. 8, 1929, pp. 47–58) together with a first installment of the discussion received. The report begins with a review of the many unsettled, and sometimes mysterious, questions of cutting fluid performance which led to the necessity for a general program of research. Afterward there is given a brief outline of some results already obtained from the preliminary experimental work. The report concludes with two appendices containing (1) a classified bibliography of cutting fluids literature (64 references); and (2) a blank chart for tabulating current shop practice in the use of cutting fluids.

Progress Report No. 2 of the sub-committee, compiled by S. A. McKee, and entitled "Present Practice in the Use of Cutting Fluids," is scheduled for presentation and discussion at the annual meeting of the American Society of Mechanical

Engineers, on Tuesday afternoon, December 3, 1929. Preprints can be obtained from the above society, 29 West 39th Street, New York, N. Y. This report is based upon information contributed by 68 of the large users of cutting fluids in this country. More than 12,000 individual returns were actually utilized in compiling the nine tables presented in the report. The first table lists the number of plants using any of three general types of cutting agent (dry cutting; water or water emulsions; and oils or oil mixtures) for each of nineteen machining operations on eight kinds of metals. Each of the remaining tables gives more detailed information regarding the cutting agents used for the various operations on a given metal.

The following basic materials had been used in making up the numerous cutting agents reported: water, soda, animal fats and oils, vegetable and mineral oils, carbon tetrachloride, turpentine, sulphur, soap, white lead, beeswax, talc, lamp black, petrolatum, and compressed air (in the form of air-blast).

The statistics obtained illustrate the chaotic condition of present-day American practice mentioned above and suggest the importance of experiments which will make it practicable to classify and specify cutting fluids on the basis of their essential physical properties such as oiliness, viscosity, thermal conductivity, and the like, rather than on the basis of chemical composition. This requires experiments on cutting of metals planned in such a manner as to bring out whatever correlations may exist between a minimum number of basic physical properties on the one hand and the measured cutting performance of the fluid, on the other hand. Quantitative relations are ultimately sought for, such as have already been successfully obtained in the field of bearing lubrication. It is recognized, however, that the problems of cutting fluid performance are inherently more complex than the analogous problems of bearing lubricating.

THE STORMER AND OTHER ROTATION VISCOMETERS.

For measuring viscosity either the capillary tube or the rotation viscometer is generally used. Much less has been written about the latter than about the former type of instrument.

The essential requirement of a rotation viscometer is that there shall be relative motion between two parallel surfaces, and this is most readily attained by the use of two coaxial cylinders. If d_1 is the outside diameter of the smaller cylinder and d_2 the inner diameter of the larger cylinder, the cylinders are separated by a space of thickness $\frac{d_2 - d_1}{2}$ which is filled with the liquid to be tested. With such an instrument, assuming that there is no friction, turbulence or "end effect" (i.e., assuming that the viscous resistance is the same as for a portion of equal length of an infinitely long cylinder), the absolute viscosity is given by the equation

$$\mu = \frac{30Wgr(d_2^2 - d_1^2)}{\pi^2 h N d_2^2 d_1^2} = \frac{CW}{hN}, \qquad (1)$$

where μ = absolute viscosity in poises.
Wgr = turning moment in dyne centimeters due to a weight or weights W, in grams, acting at an effective radius r in cm.
h = height of cylinder, in cm., wetted by the liquid.
N = speed of rotating cylinder, in revolutions per minute.

Equation (1) is valid either when the inner or the outer cylinder rotates. With the Stormer viscometer the inner cylinder is rotated by a weight, while the outer cylinder is stationary. With the improved MacMichael viscometer[1] N is the speed of rotation of the outer cylinder, the inner cylinder being stationary at the time the reading is made. As the Stormer viscometer is ordinarily used with the inner cylinder totally submerged, the wetted height can not be varied and, therefore, the end effect can not be evaluated.

In cases where the inner cylinder is not submerged and equation (1) is applicable, the rate of shear is equal to $\frac{\pi d_2^2 d_1^2 N}{60(d_2^2 - d_1^2)R^2}$, where R is the distance from the axis of rotation to any point under consideration. The mean rate

[1] "The Improved MacMichael Viscometer," Winslow H. Herschel, *Jour. Optical Soc. of America* and *Rev. Sci. Insts.*, Vol. 7, p. 335, 1923 (U. S. Patent No. 1,236,706 of Aug. 14, 1917).

of shear over the entire cross section is given by

$$\frac{\pi N d_2^2 d_1^2 \log_e \frac{d_2}{d_1}}{7.5(d_2^2 - d_1^2)^2}.$$

It should be noted that the rate of shear, although expressed in radians per second, must not be confused with the speed of the rotating cylinder, which, expressed in the same unit, is equal to $\frac{2\pi N}{60}$.

The practical difficulties arising in the construction of this theoretically simple instrument are those connected with the exact measurement of the small turning moments involved, avoidance of turbulence, and the evaluation or elimination of frictional forces. The end effects are usually evaluated by two or more measurements of viscosity with different wetted heights. The instrumental constant, C, may then be calculated from the dimensions. The constancy for the values for viscosity of a simple viscous liquid at different rates of shear, after the end correction has been applied, is sufficient evidence of the correctness of the design.

The following directions indicate the usual method of reporting results with the Stormer viscometer:

"Take the time for 100 revolutions with water as unity. Then the relative viscosity of another fluid will be the time required for 100 revolutions divided by the time for 100 revolutions in water. If a liquid is found too viscous for comparison with water, first determine the viscosity of an intermediate liquid as standard. After this calculate back to water as unity."

This use of so-called relative viscosity is objectionable because viscosity is not proportional to time unless there is no turbulence, which can not be assumed with water.

Since some time is required to accelerate the inner cylinder, it should be allowed to attain a constant speed before starting to measure the time for 100 revolutions. From equation (1) the viscosity should be proportional to the product of the driving weight by the time for 100 revolutions, but some method of correcting for pivot friction is necessary. Higgins

and Pitman[2] using a modified form of equation, found for their Stormer instrument,

$$\text{viscosity in centipoises} = 4.6t - 25, \quad (2)$$

which applies when a 150 gram weight is used, and

$$\text{viscosity in centipoises} = 9.3t - 30 \quad (3)$$

for use with a 300 gram weight. These equations do not apply for viscosities below 15 centipoises, but a diagram given by them for use in place of equation (3) for determining lower viscosities.

If t, the time in seconds, for 100 revolutions, is corrected for friction, a simple general equation, applicable even at low viscosities, may be used. With Higgins and Pitman's data, fairly concordant results may be obtained if this time correction is assumed as 4.5 seconds. Then the general equation for their instrument, with either weight, is approximately,

$$\mu = 0.000313WT, \quad (4)$$

where T is the corrected time for 100 revolutions and is equal to $t - 4.5$ seconds, W is the driving weight in grams, and μ is the viscosity in poises.

ORIFICE METERS FOR MEASURING LARGE VOLUMES OF GAS.

ON page 11 of Technical News Bulletin No. 142 (February, 1929) a general statement was given on the progress up to that time of the orifice meter investigation which has been carried on for several years by the measurement committee of the natural gas department of the American Gas Association in cooperation with the Bureau of Mines and the Bureau of Standards. During the past year considerable progress has been made towards completing the program of work which the committee has been following.

The first important step was a short series of high pressure tests which were made in the Buttonwillow gas field, near Taft, California. In these tests the line pressures were increased to over 600 lbs./in^2. Several tests were made on

[2] "Measurement of Viscosity of Pyroxylin Solutions," E. F. Higgins and E. C. Pitman, *Jour. Ind. & Eng. Chem.*, Vol. 12, p. 587, 1920.

samples of the gas to determine the super-compressibility factor, that is, the amount by which the gas deviates from Boyle's law. As a result of these tests it was concluded that if the super-compressibility factor is correctly determined and applied to the meter computations, measurements by orifice meters may be made at high static pressures with the same degree of accuracy as at low pressures.

The next step was a series of tests at low pressure, on 16, 8, and 4 inch lines. These three test lines were used successively in series with a bank of 10 inch lines which were used as reference meters. The set-ups for the three lines were made as nearly geometrically similar as was conveniently possible without excessive alterations in the rest of the piping system. There were three important elements associated with these tests: First, it was possible to obtain almost any rate of flow up to 2,000,000 cubic feet per hour. Second, because of this large flow it was possible to extend the ratio of orifice to pipe diameter to 0.86 (e.g., a 7 inch orifice in the 8 inch line), and in the case of the 4 and 8 inch lines, to increase the gas velocity through these large orifices up to about the critical velocity. Third, the same set of reference lines could be used throughout and the set-up conditions for the three sizes of lines were approximately geometrically similar.

The most important conclusion that may be drawn from a preliminary study of the results is, that for the same diameter ratios the value of discharge coefficient of an orifice is independent of the actual pipe size, *provided* the installations are geometrically similar including the design and location of straightening vanes. It also appears that when the static pressure is taken on the upstream side of the orifice, the coefficient-pressure ratio curve is very nearly a straight line.

In this investigation the bureau was fortunate in having the hearty cooperation of the industry, the assistance rendered by the Pacific Coast Gas Association and the California Natural Gasoline Association being particularly important.

PREPARATION OF VERY PURE PLATINUM SPONGE.

THE bureau has completed the preparation of about 500 grams of very pure platinum sponge. This preparation served once again to show the effectiveness of the method for the purification of platinum developed at the bureau and published in *Transactions American Institute of Mining and Metallurgical Engineers*, Vol. 76, p. 603; 1928. The starting material in this case was scrap platinum containing about 5 per cent. of impurities, which included iridium, rhodium, palladium, ruthenium, gold and iron, and doubtless small amounts of other metals. Gold was first precipitated by the addition of ferrous sulphate, after which the iron thus introduced, together with the other impurities mentioned, were precipitated by the addition of sodium bicarbonate to the boiling solution until it was very faintly alkaline. As described in the published method, sodium bromate was previously added to retard the reaction between platinum and the sodium bicarbonate. In the filtrate from this precipitation, platinum thus obtained was apparently at least 99.999 per cent. pure. A second ammonium chloride precipitation was made for the purpose of eliminating the sodium chloride which was carried down in the first precipitation. The presence of small amounts of sodium chloride or similar salts in platinum sponge prevents the successful melting of the sponge in the high frequency furnace. So far as could be detected, however, the re-precipitation with ammonium chloride did not show the presence of any heavy metal impurities in the platinum. While this method of purification requires some experience in manipulation, it is very well suited to the rapid preparation of very pure platinum on a laboratory scale. There is no apparent reason why it could not be adapted to small scale and possibly even to full scale commercial refining of platinum.

WAIDNER-BURGESS STANDARD OF LIGHT.

THE pyrometry section of the bureau has succeeded in setting up a fundamental standard of light to which other standards can be referred, following the procedure suggested by Waidner and Burgess in 1908.

This standard involves the use of a hollow enclosure (black

body) immersed in a bath of molten platinum. Observations are taken of the light emitted from the interior of this enclosure during the period of solidification of the platinum. This proposal was recognized from the first, as ideal, but seemed to present such experimental difficulties as to discourage any attempts actually to carry it out.

In order to withstand the extremely high temperature at which platinum melts—1,772° C. (3,220° F.)—a special refractory (fused thorium oxide) was developed. This accomplishment, together with recent improvements in high-temperature technique, such as the use of the high-frequency induction furnace, enabled the bureau to overcome seemingly insurmountable difficulties and to reduce the operation of the apparatus to a matter of laboratory routine. The brightness of the Waidner-Burgess standard in terms of the average value of the bureau's carbon lamp standards, was found to be 58.9 International Candles per square centimeter.

The great practical advantage of the Waidner-Burgess standard is the fact that it is based upon a fundamental constant of nature and will not change with time. It therefore offers a basic standard to which incandescent lamp standards can be referred if desired. The successful experimental realization of this standard prepares the way for a proposal that it be adopted as an international standard. The outcome of such a proposal would, of course, depend upon the action of the various national laboratories and others concerned.

ULTRA-VIOLET SOLAR RADIATION.

In connection with the bureau's investigation of the properties of special window glasses and glass substitutes for transmitting ultra-violet solar radiation of wave lengths less than 310 millimicrons, measurements were made at two elevations (7,250 and 10,500 feet) at Flagstaff, Ariz., to determine the amount of incoming ultra-violet radiation at these higher elevations as compared with a station practically at sea level—Washington. An interesting result is the observation that, while the spectral quality of the ultra-violet at the 10,500 feet station is appreciably different (being richer in short wave-length ultra-violet) from that at the 7,250 feet

elevation, the total amount of ultra-violet, of wave-lengths less than 310 millimicrons, for unit air mass, is practically the same at these two stations. This is the result of the increased scattering of ultra-violet radiation at the lower (7,250 feet) elevation.

PROTECTION OF ELECTRICAL CIRCUITS AND EQUIPMENT AGAINST LIGHTNING.

THE bureau has issued as Miscellaneous Publication No. 95 a report dealing with the application of lightning arresters to electrical lines and equipment. The report has been drawn up by a committee of experts representing the various technical societies and others concerned with this subject. The protection of power, railway, signaling, and communication circuits and apparatus is described. The bulk of the report deals with the application of lightning arresters to power and railway circuits but other methods of protection, such as the use of overhead ground wires, are also discussed.

Not only direct strokes of lightning but induced surges upon overhead conductors produce a great deal of trouble in the operation of the electrical utility services. This report points out how a proper selection and application of lightning arresters will greatly reduce such troubles and enable the utility companies to avoid frequent interruptions to their service from this cause.

The bureau wishes to emphasize the fact that this is only a preliminary report. Comments and suggestions from those interested will be welcomed. The investigation of the properties of lightning is now being carried out more intensively than ever before, and it is expected that within a short time our knowledge of lightning and of the methods of combating its effects will be greatly increased.

Copies of this publication may be obtained from the Superintendent of Documents, Government Printing Office, Washington, D. C., at 25 cents each.

FIRE RESISTANCE OF PLASTER PARTITIONS.

A NUMBER of fire tests of solid and hollow plaster partitions, built by applying plaster on metal lath attached to metal studs, have been made recently in the bureau's small wall and partition furnace. The object of the tests here reported was primarily to learn the effect of different proportions of gypsum and sand in the plaster on temperature transmission through the partition. The solid partitions were built on a single layer of No. 24 gage lath (weighing about 3 pounds per square yard) attached to ¾-inch plastering channels spaced about 12 inches apart. After the first scratch coat of plaster had set, one or more body coats were applied on each side to attain the desired thickness. For the hollow partitions, two metal lath and stud backings were spaced three inches apart by means of solid channel spacers, and two coats of plaster applied on the outside of each to give a plaster thickness of about ¾ inch. The proportions of mix for the plaster were determined by dry weight of gypsum plaster and sand, respectively. No whitecoat finish was applied, the outer brown or body coats being floated to a smooth surface. The partitions were seasoned from 30 to 40 days under dry room conditions before testing.

The partitions were tested as non-bearing partitions with fire exposure on one side controlled according to the standard testing procedure. The temperatures on the unexposed side were determined by means of thermometers under asbestos felt pads 0.4 inch thick and by means of thermocouples attached to the bare surface. The ultimate fire resistance of all of these partitions was determined by an average temperature rise under the asbestos pads of 139° C. (325° F.) above the initial temperatures. No cracks were formed of sufficient size to pass flame or smoke.

The following table gives the ultimate fire resistance of the partitions as determined on the above basis. The periods have been rounded to the nearest 5 minutes and have been corrected so as to apply for even thicknesses of 2 and 2½ inches for the solid partitions. This was necessary as the partitions, as constructed, varied by ⅛ to ¼ inch from these nominal thicknesses.

Ultimate Fire Resistance of Plaster on Metal Lath and Metal Stud Non-Bearing Partitions.

Type.	Plaster proportions by dry weight.	Thickness.	Ultimate fire resistance.	
		Inches.	Hours.	Minutes.
Solid	1 gypsum: 3 sand	2	—	45
Solid	1 gypsum: 2½ sand	2	—	50
Solid	1 gypsum: 2 sand	2	1	00
Solid	1 gypsum: 2½ sand	2½	1	10
Hollow	1 gypsum: 2½ sand; plaster ¾ inch thick on each side	4½	1	15

An appreciable gain in fire resistance is secured by increasing the gypsum content of the plaster from the 1:3 to the 1:2 proportion. The gypsum in the plaster aids materially in retarding the temperature rise in the partition, since the hydrated plaster, $CaSO_4 \cdot 2H_2O$, is changed by loss of combined water to $CaSO_4 \cdot \frac{1}{2}H_2O$ (plaster of Paris) or $CaSO_4$, depending on the temperature. This molecular change absorbs heat and the vaporization of the water set free further retards the temperature rise, particularly above 100° C. (212° F.). The 2½ inch solid partition is seen to give nearly the same fire resistance as the hollow 4½ inch partition. The former is less expensive to construct although proper proportion and consistency of plaster must be used if sagging of unset plaster is to be prevented where the full thickness is applied over the scratch coat in one day.

The partitions (4 feet 2 inches square) were smaller than the minimum size required for a standard test, but in the case of the partitions concerned it is believed that this will not introduce very significant differences in results. Well-set gypsum plaster applied on metal lath is not subject to spalling or similar disruptive effects on exposure to fire. These effects where they do occur are more likely to be destructive to the larger panel. No indication of spalling or separation of coats appeared in any of the partitions tested.

No hose stream was applied in the tests, ability to resist which is one of the requirements for a partition construction. Similar partitions have, however, been subjected to hose streams in tests elsewhere with indications of resistance sufficient for the classifications involved.

Further information on the above points will be developed in a series of fire tests of interior partitions to be undertaken in the bureau's new wall furnace which is now being constructed. This will accommodate a partition 16 feet wide and 11 feet high. Means are being provided for applying load to bearing partitions as well as for conducting hose stream tests.

A STUDY OF DESIGN FACTORS OF HOLLOW WARE DIES.

IN the bureau's study of machines for extruding clay columns, the first part of the investigation pertaining to brick dies has been completed, and the results were published in the *Bureau of Standards Journal of Research* (Vol. I, No. 6, p. 1023, December, 1928).

The second part of the investigation concerning the design factors of hollow ware dies has been undertaken, and in connection with this investigation a study of methods of lubrication is also being made.

Special equipment has been developed for studying taper and length of dies and cores, and also for determining the moisture content and density of the molded product.

Data obtained indicate that the most efficient hollow tile die, expressed in quality of product and economy of power consumption, is not over 3 inches long, with cores not over $1\frac{1}{2}$ inches long, both cores and die having a taper of approximately three degrees, that is an angle whose tangent is 0.0524.

Taper affects column structure more than it does power consumption. Both core and die length have a marked effect on power consumption without producing a proportional improvement in column structure. Hollow ware dies that are too short produce columns with transverse cracks and torn corners.

Design information obtained from a number of preliminary lubrication tests, in which an improvised lubricated hollow tile die was used, has been incorporated in the construction of an experimental hollow tile die having the ingress tapered six degrees for a length of three inches, the remaining three inches of length being straight. The egress of this die can be reduced to one inch in length in steps of one-half inch.

Data obtained in recent tests where compressed air, steam, water, and oil were used as lubricating agents introduced 5 inches back of the egress, indicate that steam and air are the most efficient for increasing output and decreasing power consumption without detriment to column structure. The other two lubricants are each substantially equal in reducing power consumption, but noticeably less in this respect than steam or air.

The maximum working pressures of the four lubricants as measured at the die in pounds per square inch in sequence with the extrusion tests and flow tests are: compressed air 16, steam 12, water 10, and oil 10. The corresponding flow pressures of the material measured in pounds per square inch required to extrude through a half inch orifice are approximately 46, 50, 55, and 56. The gradual increase in flow pressure and corresponding internal die pressure were largely the result of a gradual total moisture drop of about one per cent. as the material was repeatedly extruded. The two compressible lubricants are injected at about one-third and one-fourth the corresponding flow pressure respectively, whereas it was necessary to inject the two liquids at pressures about one-fifth the flow pressure in order to prevent injury to the clay column caused by excessive lubricant pressure. Sufficient data have not been obtained up to the present time to warrant making definite deductions regarding lubrication.

NOTES FROM THE RESEARCH LABORATORY, EASTMAN KODAK COMPANY.*

THE PLASTICITY OF SOLVATED COLLOIDS.[1]

S. E. Sheppard and R. C. Houck.

EXPERIMENTAL evidence is given to show that the plasticity of sols of solvated colloids may be made zero by adequate peptization. With cellulose derivatives this can be secured by using a polar-non-polar solvent mixture just able to homologate the polar-non-polar groups in the macromolecule. Disturbance of the solvation balance makes the solution show viscosity and plasticity of anomalies. It is suggested that the structure of the sols is such that even in concentrated solutions the macromolecules are separated from each other by oriented solvent molecules although forming swarms. Isomeric differences together with differences of polarization (chain length) account for the high degree of specificity shown by the high molecular colloids.

TINTED FILMS FOR SOUND POSITIVES.[2]

L. A. Jones.

THE tinted bases which have been used in the past for the manufacture of positive motion picture film, in many cases absorb the radiation to which photo-electric cells are sensitive to such an extent as to prohibit their use for making sound-on-film positives. In the manufacture of the new tinted bases described, the dye formulas used have been adjusted to eliminate this objection and, at the same time, give sufficient selective absorption within the visible spectral

* Communicated by the Director.

[1] Communication No. 382 from the Kodak Research Laboratories and published in *J. Rheology*, 1: 20 (1929).

[2] Communication No. 393 from the Kodak Research Laboratories and published in *Trans. Soc. Mot. Pict. Eng.*, 13: No. 37, 199 (1929), and *Proj. Eng.*, 1: 29 (1929).

region so that satisfactory color effects are obtained. Practical tests indicate that a tinted base having a photo-electric density of 0.3 can be used without serious depression of the sound volume, moreover, it has been found in the case of different tints following each other in sequence that a variation in photo-electric density of from 0.10 to 0.30 does not produce serious disturbances of the volume levels. These limits were, therefore, adopted, and the seventeen tinted bases have photo-electric densities lying between these limits. The sixteen chromatic tints are spaced tints are spaced fairly uniformly on the hue scale, thus giving a complete gamut of colors available for use in the making of sound positives. The hueless tint (Argent) is so adjusted as to have a photo-electric density approximately equal to the mean of the sixteen colored bases. The desired result is accomplished by choosing dyes and dye combinations which have relatively low absorption in that spectral region to which the photo-electric cell is most sensitive. The use of these colors on the motion picture screen is discussed at some length from the standpoint of their emotional values. A brief summary is given of the present knowledge of the language of color and the various psychology factors involved.

NOTES FROM THE U. S. BUREAU OF MINES.*

CHLORATE EXPLOSIVES.

THE Bureau of Mines is not infrequently called upon by consumers of explosives, usually quarrymen, to give an opinion on an explosive offered for use, the correspondent supplying only the name under which the explosive is offered and, occasionally, adding "it is said to be a chlorate explosive" or "it contains chlorate of potash and sugar" or other general statements of this nature.

Considering how easy it is to make explosive mixtures and to coin names for them it is obvious that no definite opinion can be safely based on such casual information, but there is much general information regarding chlorate explosives on record and since chlorate explosives are so easy to manufacture and, since, as a rule, they are very unsafe and have caused much loss of life and property and injury to persons, their general characteristics should be made widely known so that everyone may be on guard against them.

Potassium chlorate is a colorless, highly crystalline salt which is easily produced by the electrolysis of potassium chloride, and as the raw material for its production exists in very large quantities as mineral deposits in the earth, the supply is most abundant, states Dr. Charles E. Munroe, Chief Explosives Chemist, Bureau of Mines. When the solid potassium chlorate is heated it melts and, at a temperature of only about $3\frac{1}{2}$ times that of boiling water, begins to decompose and evolve oxygen. Consequently if the chlorate is mixed with combustible substances the latter will burn in the oxygen which is thus set free and the reactions of decomposition and combustion will go on at so rapid a rate that an explosion ensues. In fact the reaction goes on with such rapidity as to produce a detonation comparable with that developed in the explosion of dynamite.

Although potassium chlorate had then long been known, it was Claude Berthollet, an eminent French chemist, who,

* Published by permission of the Director, United States Bureau of Mines.

in 1786, developed a method for manufacturing it in a state of purity and from his investigations of its properties he, in 1788, advocated its being substituted for potassium nitrate in the manufacture of gunpowder. He undertook the manufacture of this powder in the powder mills of the French Government at Essone with the result that during the mixing, or "incorporating," the mass exploded with fatal results.

Experience has shown that mixtures of potassium chlorate, such as the above, or with other combustible substances, are extremely sensitive to explosion by friction, percussion or concussion, and ignition, or to contact with free acid. Marcelin Berthelot has shown that potassium chlorate is even explosive by itself, by dropping the melted salt on a sheet of iron heated to redness, the chlorate exploded with great violence as it touched the hot iron.

Although sensitiveness to explosion by friction or impact, or by frictional impact such as results from a glancing blow, may be a most desirable quality for initiators to possess, it is a most objectionable and dangerous characteristic in an explosive for use in blasting, since in shoving the charge into a borehole and in the subsequent stemming and tamping the explosive, if sensitive, is likely to be exploded. Accidents attendant on the loading of boreholes were so frequent that as chemists began devising methods for gaging the relative safety of explosives attention was given to tests for sensitiveness to explosion by frictional impact with the result that the Germans adopted a test based on the rubbing of a minute mass of the explosive in a small unglazed porcelain mortar with an unglazed porcelain pestle. Dr. Dupre, on behalf of the British Government, devised the test of spreading a small quantity of the explosive on a stone table top and striking the explosive a glancing blow with a mallet. Two mallets, one with a beechwood head and the other with a head of rawhide, were used to distinguish different degrees of sensitiveness. This was supplemented by using a broomstick in place of the mallets and of a wooden top table in place of stone.

The explosives experts of the U. S. Bureau of Mines, while thoroughly approving of the Broomstick Test and having full confidence in the results Dr. Dupre obtained with it,

yet doubted if many other persons would obtain in its use results identical or closely approaching those of Dr. Dupre. Consequently they set about embodying the principles of the broomstick test in a mechanism that could be operated uniformly, with the result that the U. S. Bureau of Mines Pendulum Friction Device was developed in 1911 and has been in constant and successful use ever since. The essential feature of the device is a pendulum, of known length and weight, varied as desired, arranged to swing from different predetermined heights, and having a bob of steel, or hard wood, or rawhide as desired. And this pendulum is set to swing across a corrugated steel anvil upon which the weighed quantity of the explosive to be tested is placed.

Notwithstanding the inauspicious beginning attending the making of chlorate powders, in the upwards of 150 years that have intervened since Berthollet made his disastrous demonstration, hundreds of persons have attempted to produce propellents to replace gunpowder or blasting explosives as substitutes for blasting powder and dynamite through the use of potassium chlorate or other chlorates. Of the hundreds of compositions that have been devised for these purposes, however, only two, namely rack-a-rock and cheddite, seem to have met with any measure of commercial success. This is the more remarkable since rack-a-rock, on its introduction to the public, received a most unusual degree of publicity, for it was the principal explosive used in the spectacular blast that razed Hell Gate. Rack-a-rock is peculiar in that it is manufactured at or near the place where it is to be fired. It is made by putting a weighed quantity of potassium chlorate in a cartridge case and pouring in upon the crystals a weighed or measured quantity of liquid mono-nitro-benzene. Or preferably the cartridge case, containing its charge of chlorate, is immersed in the liquid mono-nitro-benzene until, by weighing, it has been found to have absorbed the necessary amount of the liquid to produce the desired explosive mixture. The charge is then ready to be placed in the borehole.

Although over 240,000 pounds of rack-a-rock were fired in the blast at Flood Rock, Hell Gate, N. Y., October 10, 1885, very little has been heard from it since that day. Oc-

casionally accounts appear of its use in remote mining regions where it is difficult or unsafe to transport and store explosives. Evidently as made and used rack-a-rock involves the minimum of exposure to friction and percussion, and if the nitrobenzene is acid free the likelihood of spontaneous explosion is remote, but the dipping operation attending manufacture is found inconvenient, and there have been instances of persons becoming poisoned by inhaling nitrobenzene or from its contact with the skin.

There was much surprise expressed among those especially interested in explosives when, in the later years of the 19th century, it was learned that a chlorate powder called cheddite had passed the "Dupre broomstick test" at the hands of Dr. Dupre himself. This explosive is produced by dissolving nitrosubstitution compounds, such as a nitronaphthalene and a nitrotoluene, in a heated oil, such as castor oil, and then by means of a wooden paddle stirring into the solution finely powdered and well dried potassium chlorate until they are thoroughly mixed. After cooling somewhat the mixture is stirred on a board to granulate it. It is then sifted and powder of the desired granulation is packed in paraffined paper cartridge cases as dynamite is. Experience has shown that in warm weather and in hot climates the nitro-substitution compounds in cheddite tend to melt and run out of the cartridge cases, or, in other words, to exude, and exudation is a bad characteristic in an explosive. Cheddite also shows a tendency to become insensitive to detonation as its density exceeds a certain critical value. Hence great care must be exercised in tamping both the charge and the stemming lest the charge becomes so compressed that it will fail to fire. A general objection to all chlorate explosives is that they tend to produce hydrochloric acid as a component of their explosion products and this gas is very objectionable to inhale and may do injury to miners underground.

Chemistry has disclosed the possibility of preparing a large number of chlorates, besides potassium chlorate, and many of them, and particularly the sodium and ammonium chlorates, have been used in admixture with combustible substances to form explosives. These were easily produced but were found to possess the same objectionable and dangerous

characteristics of sensitiveness to percussion, concussion and friction, and to easy decomposition by acids which are the serious defects of most potassium chlorate mixtures.

Because sodium chlorate is easily produced by the electrolysis of common salt, this substance has been given special attention and in the tests of it on a large manufacturing scale another menacing effect of chlorates was emphasized. In the making of cheddites particularly, as well as in the making of most chlorate mixtures, the chlorate is ground very fine with the result that great clouds of chlorate dust are produced in the grinding process. Naturally, this dust settles on everything about the mill and particularly on the clothes of the workmen with the result that they soon become clad in exceedingly inflammable and, perhaps, explosive garments. Hence if by any chance a spark is struck, or a static charge is discharged from a belt, or ignition results from any other accidental cause, workmen so clad must almost certainly suffer serious, if not fatal injuries.

Chlorates have been used quite extensively in the manufacture of percussion caps and primers, detonators and many fireworks compositions, yet in this industry they have also given rise to many accidents, some of quite serious proportions. Investigation of these accidents have shown many due to the use of sulphur, particularly sublimed sulphur, or to ammonium salts, such as ammonium chloride, in these mixtures because of their acid containing or producing characters, for as sulphur is sublimed a part of it is oxidized to an oxide which forms an acid with the moisture in the atmosphere, while ammonium salts are decomposed by moisture from the atmosphere and yield acids. It has repeatedly happened that by the slow reaction of small quantities of acids from sources such as these, that chlorate mixtures in storage, and under other circumstances, have "spontaneously" ignited and exploded.

There is another class of chlorine compounds styled perchlorates, which serve admirably as oxidizing agents and which, provided they are pure, are free from many of the dangerous characteristics of the chlorates. It is especially essential that they contain no chlorates whatever, which, since they are also produced by electrolysis from the chlorides,

they are prone to contain. Perchlorate powders, like chlorate powders, may evolve hydrochloric acid among their explosion products, but in times of emergency, as during the Great War, they have been made use of in underground mining to a considerable extent, and with a measure of success.

It is pretty generally known that today and for some twenty years past the U. S. Bureau of Mines has made "Permissibility Tests" of explosives in which explosives submitted by manufacturers are tested in accordance with a predetermined and approved plan as set forth in Bureau of Mines Schedule 17A of May 16, 1927, to determine their safety for use in coal mines.

It is not so generally known that the Bureau of Mines also conducts "Suitability Tests" as set forth in Bureau Schedule 1B of April 3, 1926. By taking advantage of the opportunities afforded by the schedule any one inventing an explosive can have its properties tested and officially reported upon, or a prospective consumer can have such tests made as will inform him of the characteristics of an explosive he has under consideration for use. The chief difference between the two categories is that under the law the Director of the Bureau of Mines officially approves explosives which pass the permissibility tests and authorizes their publication on the Permissible List with a record of the test data for their more important characteristics, but no authorization for approval or publication exists for other explosives than Permissibles.

However, the maker or the user of an explosive can with small expenditure of effort and money ascertain whether or not the explosive will pass the test with the Pendulum Friction Device and this is the critical test for chlorate explosives.

MEASUREMENTS OF EARTH RESISTIVITY.

THE value of ground resistivity measurements made on the surface of the earth as an index of structure below it is gradually becoming of increasing importance. While originally of direct interest to the mining engineer in the location of ore deposits it has found further applications in the location of various electrical resistivities. The functioning of power service and telephonic communications are more or less af-

fected by the position of the various earth's resistivities relative to each other. The location of proper bridge, dam and building foundations with the aid of resistivity measurements is today an accepted procedure.

Although the procedure of measurement is relatively simple, interpretation of the results involves a large amount of study. Because of the great variety of discontinuities which embrace the ground structures, involving both a change of dimension as well as electrical properties, no simple mathematical system of analysis can be applied directly to these measurements. A new mathematical tool must be invented to meet these needs, hence the results must rest for the present upon extensive experimental work rather than possible theoretical deductions. Some of the difficulties encountered are set forth in Information Circular 6171, by Frederick W. Lee, J. W. Joyce, and Phil Boyer, just published by the Bureau of Mines.

For purposes of measurement two systems of determining the average resistivity of the earth are used. Their difference rests upon the type of boundary surface between which the material is located whose average resistivity is to be measured. The surfaces may be defined as nonenveloping, or as enveloping. In both cases ideal geometric configurations are assumed, and the average resistivity is computed upon this basis.

This geophysical method differs from the older one which mapped the electrical potential fields on the surface of the ground and from the form of these fields interpreted the materials associated with them but did not consider the numerical evaluation of these fields in terms of the associated material. The index number associated with the current and potential field in this circular is the resistivity. Furthermore, the resistivity can be measured separately from specimens taken from the ground and thereby allow direct correlation to those measurements made from the surface of the earth.

BLASTING DOWN COAL WITH LIQUID CARBON DIOXIDE.

Blasting with liquid carbon dioxide in coal mines has been simplified by the recent introduction of a smaller shell

for holding the liquid. The new shell weighs only about half that of the original shell and is therefore easier to handle. A further advantage arises from a reduction in the diameter of the shell, because it is only necessary to drill a hole in the coal of slightly over 3 inches in diameter, whereas the old shell required a 4-inch hole.

The new model shell has been admitted recently to the Permissible List of Blasting Devices as Approval No. 2, under the conditions and requirements of Schedule 20. The safety of this device was established by tests carried out by the engineers of the Pittsburgh Experiment Station of the U. S. Bureau of Mines. In these tests the shell was discharged into explosive mixtures of gas and air; and of gas, coal dust and air contained in gallery 1. Under these conditions it did not cause any ignition of the explosive mixtures within the gallery.

The use of carbon dioxide, which is a noninflammable gas, as a blasting agent is made possible by first liquefying it under pressure and then charging it into a hollow steel cylinder whose outside diameter is 3 inches and length nearly 32 inches. Suitable means are provided for sealing the cylinder, which holds the liquid, with a mild steel disc. The new model shell, after having been charged, is placed in the borehole in the coal. The borehole is tamped with incombustible stemming in a manner similar to that employed with permissible explosives. The liquid carbon dioxide within the cylinder is gasified by means of a heating element, which is immersed centrally within the liquid. This element consists of a combustible mixture of powdered solids with an electric squid embedded therein. Wires which extend from the shell to the outside of the borehole are connected by leading wires to a single-shot permissible blasting unit. The squid is ignited by operating the blasting unit; this in turn ignites the combustible mixture of the heater element. The temperature of the liquid carbon dioxide is raised above its critical temperature so that it is changed to a gas. This change causes a very rapid increase in pressure of the gas within the shell that causes the steel disc to be sheared. The gasified carbon dioxide expands and rushes through the aperture sheared in the steel disc. Pressure is now built up in the borehole that causes a rupture of its walls, thus bringing down the coal.

THE FRANKLIN INSTITUTE.

STATED MONTHLY MEETING, NOVEMBER 20, 1929.

The regular monthly meeting of The Franklin Institute was called to order at eight-eighteen p.m., by Mr. Nathan Hayward, the President.

The President called upon the Secretary for the necessary business. He reported that since the last meeting four Resident members had been elected to membership, and three Non-Resident members. He also reported, with deep regret, the death of five of our members.

The Secretary also explained the necessity for postponing the talk scheduled for December fifth by Mr. E. E. Hunt on "Some Economic Changes," because of the inauguration of the campaign for the erection of the Benjamin Franklin Memorial and Franklin Institute Museum. He announced that the lecture was merely postponed and would probably be delivered in March.

The President then presented Mr. Harold F. Pitcairn, the speaker of the evening, who addressed the audience on "The Autogiro: Its Characteristics and Accomplishments." Mr. Pitcairn spoke before an audience which filled to overflowing the lecture hall. He described in a most interesting manner the development of the present autogiro, and predicted some of its future characteristics. The talk was followed by a large amount of questioning, in which all the members of the audience seemed to be interested.

The meeting adjourned at nine-thirty-eight p.m., with a hearty vote of thanks to Mr. Pitcairn for his delightful paper, and with an expression of the hope that it would be printed in full in the Journal of The Franklin Institute.

HOWARD MCCLENAHAN,
Secretary.

COMMITTEE ON SCIENCE AND THE ARTS.

(*Abstract of Proceedings of Stated Meeting held Wednesday, November 2, 1929.*)

HALL OF THE INSTITUTE,
PHILADELPHIA, November 2, 1929.

DOCTOR THOMAS D. COPE *in the Chair.*

The following report was presented for final action:

No. 2861: Car Retarder System.

A railroad distribution yard is one having an incoming track over which freight cars are entered and from which they are sent out over the one for which they are intended. The outgoing tracks spread out fanlike from the incoming track and in order that the cars may be readily distributed the incoming track rises on an incline, or hump, from the top of which the cars are started by a locomotive pusher and then continue to run down the slope by gravity.

The early method of controlling the speed of cars on this slope was by placing a brakeman on each car. This method proved to be both slow and dangerous

and the car retarder system, that is the subject of this report, was devised by the inventors for the purpose of increasing the speed of distribution and removing the danger incurred in the distribution.

To accomplish this a tower is placed at the point of distribution, from which the various tracks can be seen and each car sent over the proper track by the operation of remote control devices. These devices check the speed of the car by bringing brake bars against the sides of the car wheels, the amount of pressure being under the control of the tower operator by means of either an electro-pneumatic or an all electric system. This invention is described in a United States patent granted in January, 1927, to George Hannauer, then Vice-President of the Indiana Harbor Belt Railroad, and Edgar M. Wilcox, Master Car Builder.

This system is in operation on a number of railroads and is reported to be satisfactory.

The award of the George R. Henderson Medal was recommended to Mr. George Hannauer, President of the Boston and Maine Railroad, and Mr. Edgar M. Wilcox, Secretary of the Hannauer Car Retarder Company, "in consideration of their contributions to railway engineering in the development of their car retarder system."

The following reports were presented for first reading:

No. 2889: Gibson Method of Measuring Liquid Flow.

No. 2914: Photography of Lightning.

GEO. A. HOADLEY,
Secretary to Committee.

MEMBERSHIP NOTES.

ELECTIONS TO MEMBERSHIP.

(*Stated Meeting, Board of Managers, November 20, 1929.*)

RESIDENT.

DR. R. EKSERGIAN, Engineer, E. I. DuPont de Nemours and Company, Wilmington, Delaware. For mailing: 23 Owen Avenue, Lansdowne, Pa.

MR. S. FELTON GROVE, Chief Chemist, Henry Bower Chemical Mfg. Company, 2815 Grays Ferry Road, Philadelphia, Pa.

MR. LINN HELANDER, Mechanical Engineer, Westinghouse Electric and Mfg. Company, Lester, Pa. For mailing: 652 Eleventh Avenue, Moore, Delaware County, Pa.

MR. EDMUND ROWLAND, Chemical Engineer, Bower Chemical and Manufacturing Company, 2815 Gray's Ferry Road, Philadelphia, Pa.

NON-RESIDENT.

DR. HAL TRUEMAN BEANS, Professor of Chemistry, Columbia University, New York City.

DR. HAROLD W. ELLEY, Chemist, Chemical Director, Dyestuffs Department, E. I. DuPont de Nemours and Company, Wilmington, Delaware. For mailing: Box 525, Wilmington, Delaware.

MR. JOHN HOHENADEL, Mechanical Engineer (Retired), Byron Hotel, Atlantic City, N. J.

CHANGES OF ADDRESS.

MR. WALTER ATLEE, 1219 Quincy Street, N.E., Washington, D. C.
MR. EUGENE E. AYRES, JR., Swarthmore, Pa.
MR. CLINTON LLOYD BARDO, President, New York Shipbuilding Company, Camden, N. J.
MR. CARL G. BARTH, 127 Glen Avenue, Amsterdam, N. Y.
MR. EDWARD G. BUDD, JR., 216 East Sedgwick Street, Mt. Airy, Phila., Pa.
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MR. SAMUEL H. COLLOM, 72d and Powers Lane, West Philadelphia, Pa.
MR. B. DENVER COPPAGE, Engineering Department, The Viscose Company, Marcus Hook, Pa.
DR. CHESTER L. DAVIS, 519 Wentworth Avenue, Santa Barbara, California.
MR. W. A. DOUGLASS, 28 Ziegler Tract, Penns Grove, N. J.
MR. E. W. FINKBINER, Treasurer and General Manager, South Jersey Sand Company, Dividing Creek, N. J.
MR. JOHN GRAHAM FOLEY, 9935 Third Avenue, Brooklyn, N. Y.
MAJOR THOMAS H. GRIEST, 8221 Seminole Avenue, Chestnut Hill, Phila., Pa.
DR. JOHN M. HARRIS, JR., 2510 Kanawha Street, Charleston, W. Va.
MR. W. G. HENSEL, 2828 Cove Road, Merchantville, N. J.
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MR. ERNEST L. HUFF, Box 64, Tarentum, Pa.
MR. ALFRED IDDLES, 203 Orchard Way, Wayne, Pa.
MR. THEODORE F. JENKINS, 2315 Fidelity-Philadelphia Trust Building, Broad and Walnut Streets, Philadelphia, Pa.
COLONEL P. JUNKERSFELD, Room 3647—120 Broadway, New York City. c/o Stone and Webster Engineering Corporation.
MR. CHARLES F. KELLERS, 77 Highland Avenue, Montclair, N. J.
MR. WILLIAM M. KERR, 1343 Arch Street, Philadelphia, Pa.
MR. JOSEPH B. KING, JR., "The Cambridge" Apt. 1210, Wissahickon Avenue and School Lane, Germantown, Phila., Pa.
DR. S. S. KISTLER, Guericke Strasse 39 IV, Berlin-Charlottenburg, Germany.
DR. ELMER O. KRAEMER, DuPont Experimental Station, Wilmington, Delaware.
DR. GEORGE F. KUNZ, 405 Fifth Avenue, New York City.
MR. NEWTON LAMB, 122 Storch Street, Saginaw, West Side, Michigan.
MR. CONRAD LAUER, President, Philadelphia Gas Works Company, 1401 Arch Street, Philadelphia, Pa.
MR. GUSTAV LINDENTHAL, 26 Exchange Place Room 309, Jersey City, New Jersey.
MR. W. GRAHAM LITTLETON, 135 South Broad Street, Philadelphia, Pa.
MR. RUDOLPH F. MALLINA, Bell Telephone Laboratories, Inc., 463 West Street, New York City.

MR. EUGENE MERZ, 975 Park Avenue, New York City.
MR. DAVID PELTON MOORE, Patent Department, General Talking Pictures Corp., 218 West Forty-second Street, New York City.
DR. ALFRED OBERLE, Investment Building, Washington, D. C.
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MR. CARL D. PRATT, 500 Lafayette Street, Tamaqua, Pa.
MR. TALBOT M. ROGERS, 854 Buck Lane, Haverford, Pa.
MR. NICHOLAS G. ROOSEVELT, 1517 Locust Street, Philadelphia, Pa.
MR. CHARLES E. SARGENT, 173 Seem Street, Emaus, Pa.
REAR ADMIRAL W. S. SIMS, U.S.N., 26 Brimmer Street, Boston, Mass.
MR. F. W. SPERR, JR., 1628 Koppers Building, Pittsburgh, Pa.
MISS ELIZA SMITH STECK, 323 South Eighteenth Street, Philadelphia, Pa.
MR. PAUL THOMPSON, Haverford, Pa.
MR. KENNETH URQUHART, 608 New Hampshire Avenue, Norfolk, Va.
MR. FRANK L. WRIGHT, Special Products Department, The Midvale Company, Philadelphia Pa.

NECROLOGY.

Mr. William E. Helme, Philadelphia, Pa.
Mr. Henrik J. Krebs, Wilmington, Del.
Mr. John W. Lieb, New York City.
Mr. Ralph W. Pope, Great Barrington, Mass.

LIBRARY NOTES.

RECENT ADDITIONS.

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THE ELECTROMAGNETIC FIELD. By Max Mason, Rockefeller Foundation, and Warren Weaver, University of Wisconsin. xiii–390 pages, 8 vo. Chicago, The University of Chicago Press, 1929. Price, $6.

No doubt many individuals having either a direct or an indirect interest in physics have availed themselves of the opportunity to read the two very outstanding books dealing with the universe and its ultimate nature. These are: The Nature of the Physical World by A. S. Eddington and The Universe Around Us by Sir James Jeans. If a person subsequently tackles the Electromagnetic Field by Mason and Weaver, he or she will realize that where Eddington and Jeans present their material in much the same manner as the producer of a mystery play, Mason and Weaver take you behind the scenes and disclose a few of the fundamental reasons for such an apparently deep-laid plot.

This volume has as its aim, a careful and thorough exposition of the Maxwell-Lorentz theory founded on the assumption that all physical phenomena are electromagnetic. According to the authors, this theory is very fundamental in character, and for that reason its definitions and concepts must be stated with special care and precision. "The basic mathematical structure of the theory consists of a set of vector differential equations, the 'field equations' of the electron theory." The authors believe this present theory to be a forerunner of an ultimate electromagnetic theory which possibly shall be attained in the next fifty years. In order that such a task may be expedited they have diligently labored to give the students of physics a comprehensive knowledge of that

system of equations which constitute the present electromagnetic theory and have expressed the hope that those who read and understand may look toward the future with an open mind and evaluate without prejudice those inevitable new developments in the electromagnetic theory.

The book is divided into four main sections as follows: (1) Coulomb's Law and Some Analytic Consequences; (2) The Electrostatic Problem for Conductors and Dielectrics, (3) Magnetostatics and (4) The Maxwell Field Equations. Throughout these chapters will be found vectorial representations of the various forces existing between charges both individual and in complexes. In the conclusion to chapter four the authors discuss the now fast-declining belief in the æther as a mechanical medium, the possible or probable interdependence between relativity and electrodynamics and the growing opinion that electromagnetic energy is macroscopic, similar to that of gravity, and not localized as indicated in the earlier quantum concepts. The final chapter is followed by a mathematical appendix defining vectors illustrating the relations between their various functions and their application in integral transformations and vector fields. A table describing the interchanging of electrostatic and electromagnetic units is appended and is followed by a very complete formula index.

T. K. CLEVELAND.

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CURRENT TOPICS.

The Millilitre. V. STOTT. National Physical Laboratory, England. (*Nature*, Oct. 19, 1929.) At the time of the establishment of the metric system near the close of the eighteenth century the kilogramme was intended to be the mass of the quantity of water at its maximum density occupying the volume of one cubic decimetre. To Lefèvre-Gineau and Fabbroni was entrusted the construction of a standard kilogramme. They produced the "Kilogramme des Archives" which was accepted as accurately representing a kilogramme according to the original specification. Later, doubt was cast upon the exactness of their kilogramme by determinations of the mass of water having a volume of one cubic decimeter at 4° C. These ranged from 1000.475 g. to 999.750 g. It was proposed to construct a new standard kilogramme but in place of doing this the Commission Internationale du Mètre in 1872 formally decided to accept the "Kilogramme des Archives" as it then existed as the standard kilogramme. "Thus the original definition of the kilogramme was deliberately abandoned, and the kilogramme is now simply the mass of the plain cylinder of platinum-iridium alloy known as the International Prototype Kilogramme." Thus after 1872 the litre no longer was equal to both the cubic decimetre and to the volume at 4° C. of a kilogramme of water. In 1901 the litre was defined by the Third General Conference on Weights and Measures in session at Paris as "the volume occupied by the mass of one kilogramme of pure water at its maximum density and under normal atmospheric pressure." It should be noticed that this definition is itself based on the definition of the kilogramme adopted in 1872 and is quite independent of definitions of volume and length. The relation between the litre and the cubic centimetre henceforth depends upon experimental determinations. As the result of these the present accepted value of the litre is 1,000.028 $cm.^3$ This is surely correct to one or two units in the last decimal place. The smallness of the divergence of this number from the 1,000, which it was originally intended to be, is a tribute to the exactness of the work of Lefèvre-Gineau and Fabbroni employing the experimental resources of the eighteenth century.

When volumes are derived from measurements of length it is appropriate that they be expressed in terms of cubes of the unit of length, but when volumes are obtained from weighings the litre is

the obvious unit. It is unfortunate that the litre and the cubic decimetre are not exactly of the same volume, though their difference is so slight as to count only in accurate work. An additional source of confusion was introduced by Mohr in 1868 when for the calibration of volumetric glassware he called by the name of a cubic centimetre the volume occupied at 17.5° C. by the mass of water having an apparent weight in air of one gramme. In 1924 the Joint Committee for the Standardisation of Scientific Glassware recommended "That the recognised international metric units—the 'litre' (1) and 'millilitre' or thousandth part of the litre(ml)—shall be used as the standard units of volume and that standard volumetric glassware shall be graduated in terms of these units and marked 'ml' instead of 'c.c.'" Earlier than this action the Bureau of Standards had recommended the use of the milliletre for volumetric glassware. In the "International Critical Tables" densities are often expressed in g/ml instead of in g/cm³. The use of g/ml is logical since densities are commonly got by weighing and by making use of the density of water. G. F. S.

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